FINAL REPORT

Climate Change Impacts and Adaptation on Southwestern DoD Facilities

SERDP Project RC-2232

FEBRUARY 2017

Gregg Garfin
University of Arizona

Page Intentionally Left Blank

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
03/03/2017	Final Technical Report	05/11/2012 to 05/11/2017

4. TITLE AND SUBTITLE
Climate Change Impacts and Adaptation on Southwestern DoD Facilities

5a. CONTRACT NUMBER
W912HQ-12-C-0060

5b. GRANT NUMBER
N/A

5c. PROGRAM ELEMENT NUMBER
W912HQ

6. AUTHOR(S) Garfin. G.M.[1], Falk, D.A.,[1], Jacobs, K.[1], O'Connor, C.O.[2], Haverland, A.C.[1], Weiss, J.L.[1], Overpeck, J.T.[1],Haworth, A.[3], and Baglee, A.[3]

[1] University of Arizona – Tucson, AZ
[2] USDA Forest Service – Missoula, MT
[3] Acclimatise - Cardiff -UK

5d. PROJECT NUMBER
12C

5e. TASK NUMBER
0060

5f. WORK UNIT NUMBER
RC-2232

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

University of Arizona
1064 E Lowell Street, N419
PO Box 210137
Tucson, AZ 85721

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Strategic Environmental Research and Development Program
4800 Mark Center Drive, Suite 17D08
Alexandria, VA 22350-3605

10. SPONSOR/MONITOR'S ACRONYM(S)
DOD - SERDP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
N/A

14. ABSTRACT This project engaged managers across diverse DoD operations in the Southwest. Project objectives were to: develop and pilot-test approaches for climate risk assessment; evaluate climate adaptation best practices, and support adaptation planning compatible with DoD decision-making. We interacted with personnel from the Army, Air Force, Marines, and Navy, in diverse settings. We conducted case studies to test a climate change risk assessment framework and strategies for adoption of climate adaptation measures commensurate with mission success priorities. Immediate priorities dominate decisions and resource allocation, yet climate change requires planning for seasons-to-decades. There is rarely designated funding for climate adaptation; thus, managers must divert scarce funds from competing priorities. Our approach emphasizes "mainstreaming" climate adaptation, by linking it to immediate challenges facing Base management, including wildfires, flooding, and sea level rise. Linking current challenges to projected risks catalyzes more active management, and increases chances for integrating climate change risks into decision priorities.

15. SUBJECT TERMS adaptation, baseline sensitivity, climate change, climate exposure, climate services, extreme events, fire risk, severity, risk assessment, risk management, scenario based decision support, stakeholder engagement, training

16. SECURITY CLASSIFICATION OF:N/A			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Dr. Gregg Garfin
a. REPORT	b. ABSTRACT	c. THIS PAGE		435 pages	19b. TELEPHONE NUMBER *(include area code)*
					520-626-4732

Page Intentionally Left Blank

Page Intentionally Left Blank

Authors

Gregg M. Garfin
Donald A. Falk
Katharine Jacobs
Arin Haverland
Jeremy L. Weiss
Jonathan T. Overpeck
University of Arizona – Tucson, AZ

Christopher D. O'Connor
USDA Forest Service – Missoula, MT

Anna Haworth
Alastair Baglee
Acclimatise, United Kingdom

Page Intentionally Left Blank

Abstract

Objectives
Climate change is understood as a serious global phenomenon that will affect all aspects of national and global economy, society, and security. To address needs related to climate change challenges, and with support from SERDP, this project aimed to: (1) develop and pilot-test approaches for climate risk assessment; (2) evaluate climate adaptation best practices in a series of case studies, and (3) evaluate approaches and needs for climate services to support adaptation planning compatible with DoD decision-making needs and processes.

Technical Approach
We interacted with DoD personnel in risk assessment workshops and case-study pilots at four installations in the Southwest, through participatory processes. We also conducted interviews and convened workshops with personnel, in order to identify gaps, needs, and opportunities for infusing climate adaptation thinking and practice into DoD operations, and to evaluate promising approaches to climate services, that mesh with military culture, leadership, and practice. We explored current obstacles to adopting climate adaptation measures and possible solutions to overcome these obstacles.

Climate risk assessments and adaptation case studies were conducted at Fort Huachuca (FTH; U.S. Army), Barry M. Goldwater Range East (BMGR-E; U.S. Air Force), Barry M. Goldwater Range West (BMGR-W; U.S. Marines), and Naval Base Coronado (NBC; U.S. Navy). We explored in each case the influence of top-down DoD policy directives and guidance on day-to-day Base management, and what factors might determine if a given installation is likely to be an “early adopter”, or to focus more on here-and-now priorities to the exclusion of long term adaptation planning. We conducted detailed case studies, at FTH and NBC to test hypotheses about strategies for encouraging adoption of climate adaptation measures in the context of Base management priorities and resources.

To fulfill Project objectives, we designed and implemented activities as follows:

1. We tested methods to **assess current and future climate-related impacts and risks**, including the data, information, and climate services support needed by DoD personnel, to assess climate change risks and vulnerabilities.
2. To demonstrate proof of concept for supporting DoD decision-makers, we **tested readily accessible and publicly available data and decision tools** to generate information on climate-driven wildfire and post-fire flood risks and uncertainties.
3. We developed **installation-focused pilot projects to assess a participatory approach** to climate change risk assessment, and to co-develop, with installation personnel, strategies that are resilient in light of uncertainties. We convened a workshop of related SERDP climate change projects, and synthesized expert advice on risk assessment, decision-support, uncertainties, and the climate services needed to support decisions.
4. We **developed a science-based decision support process,** which included the co-development of strategies, along with installation resource management personnel, for management of wildland fire risk in the face of uncertainties. We assessed approaches used by analogous entities, such as international departments of defense, heavy

industries, and multi-faceted state and city governments, and summarized best practices currently being adopted by this array of climate-sensitive entities.

Results.

Assessing current and future climate-related impacts and risks. In studies at all four bases we found that integrating climate change risks into the current decision matrix, by linking projected risks to current or past impacts, creates active engagement by focusing on here-and-now challenges. Addressing specific current issues builds capacity and willingness to incorporate climate change thinking into future planning and risk management processes and builds interest in science-based solutions. Key issues addressed included potential impacts of sea level rise, wildfire, flooding, invasive species, and impacts of climate variability.

Adoption of publicly available data and decision tools and methods. Bases have some capacity to integrate climate-related information, but they have limited resources to undertake the studies necessary to assess risk comprehensively. Our project team provided summaries of relevant information to military and civilian Base personnel and management for climate variables, wildfire, flooding, and other near-term risks. At FTH we developed a partnership with the Environment and Natural Resources Division group to assess how fire management strategies might be influenced by changing climate drivers; at NBC we helped the Base evaluate potential elevated fire risk due to climate and past land-use history, using publicly available modeling tools.

In **intensive installation-focused pilot projects** we tested hypotheses of engagement. At both NBC and FTH, we focused on climate influences on near-term risks identified by Base leadership, particularly wildfire and post-fire flood risks. We found increasing wildfire risk at both bases over multi-decade periods, and in the case of FTH a strongly increasing risk of post-fire flooding due to direct climate effects on fire behavior and climate-driven changes to vegetation from persistent drought stress and increasing temperatures.

Our interactions with installations provided clear **lessons for climate change adaptation and decision-making in DoD**. Base management was receptive to climate-related actions, but day-to-day priorities dominate decisions and resource allocation. There is rarely designated funding for climate adaptation; thus, Base management must divert scarce funds for these purposes from many other competing, and often immediate, priorities. Recognizing this, we developed an adoption model that emphasizes “mainstreaming” climate into existing priorities, which enables Base managers to transition from present concerns to future and emerging problems.

Benefits.

Installations are the “front lines” of climate adaptation in the DoD. Our emphasis on installations, allowed us to develop a unique strategy tuned to the needs and challenges of this organizational level, including (1) assessing data and information needs, (2) assessing Base-wide risk, (3) engaging personnel, (4) communicating climate change information, (5) mainstreaming climate change into DoD practice and policy, (6) addressing DoD institutional norms, leadership and partnerships, and (7) providing climate services for DoD installations and supporting DoD climate services capacity. This model shows great promise to speed the incorporation of climate adaptation planning at all levels of the DoD.

Acknowledgements

This project was funded by the Strategic Environmental Research and Development Program (SERDP), and we are grateful for the continued support of the SERDP staff including John Hall, Herb Nelson, Cara Patton, Sarah Lugo, Sarah Barlow, and Catherine Simons. We would also like to thank the University of Arizona Institute of the Environment and the Center for Climate Adaptation Science and Solutions, as well as Acclimatise, our United Kingdom partners.

Our work on climate change adaptation would not have been possible without the tremendous efforts put forth by the men and women of the installations and specific sites we had the pleasure of working with during the project cycle including: Naval Base Coronado, Camp Michael Monsoor, Camp Morena, Fort Huachuca, and the Barry M. Goldwater Ranges East and West. In addition to those who aided in field activities our natural resource management liaisons Rick Whittle (BMGR-East), Abigail Rosenberg (BMGR-West), Sheridan Stone, Debbie Brewer and Shane Hall (FTH), and Arlene Arnold, Patrick McKay and Bruce Shaffer (NBC) deserve our sincerest thanks for their guidance and insights as well as their time spent towards helping to shape the project and connect us to military personnel. A series of outstanding graduate students, who have now completed their graduate studies, have also contributed to the project through comprehensive assessment and reporting tasks and include Forrest Treanor, Brian Sheppard and Adriana-Zuniga Teran.

We also wish to offer our special appreciation to Bart Chadwick and colleagues at SPARWAR, as well as to Rear Admiral David W. Titley, United States Navy (Ret.) of Pennsylvania State University for their contributions throughout the project. The RC-2232 team also recognizes the cross-project workshop participants who came together in March of 2016 to discuss and frame barriers and opportunities to mainstream climate change adaptation in the DoD context, as well as the international and domestic interview respondents who dedicated their time and experiences with the DoD.

The final report authors would especially like to acknowledge the original lead investigator and guiding light of this project for 3 years, the late Dr. Rafe Sagarin. His enthusiasm for conducting this research, and his insights as a researcher, were inspirational. Our success is due to his leadership and vision for the project; any shortcomings are our own.

Acronyms and Abbreviations

AFB	Air Force Base
AGWA	Automated Geospatial Watershed Assessment toolkit
ADF	Australian Defense Force
BMGR	Barry M. Goldwater Ranges (East, Gila Bend, AZ; West, Yuma, AZ)
BOT	British Overseas Territories
CIRAM	Climate Impacts Risk Assessment Methodology (UK Ministry of Defence)
CM	Camp Morena (inland training facility of Naval Base Coronado)
CMIP3	Coupled Model Intercomparison Project Phase Three
CMIP5	Coupled Model Intercomparison Project Phase Five
CMM	Camp Michael Monsoor (inland training facility of Naval Base Coronado)
DIO	Defence Infrastructure Organisation (United Kingdom)
DoD	Department of Defense
ENSO	El Niño-Southern Oscillation
FireBGCv2	Fire Biogeochemical Model Version 2
FTH	Fort Huachuca, U.S. Army
GCM	Global Climate Model
HOE	Head of Establishment
HVAC	heating, ventilation, and air conditioning
IPCC	Intergovernmental Panel on Climate Change
KINEROS	Kinematic simulation of catchment runoff and erosion processes
LANDFIRE	Landscape Fire and Resource Management Planning Tools
NAP	National Adaptation Plan (United Kingdom)
NARCCAP	North American Regional Climate Change Assessment Program
NBC	Naval Base Coronado
NCA3	Third National Climate Assessment
NDMI	Normalized Difference Moisture Index
NGO	Non-governmental Organization
NRM	Natural Resource Management
OSD	Office of the Secretary of Defense
PANYNJ	Port Authority of New York and New Jersey
PME	Professional Military Education
SERDP	Strategic Environmental Research and Development Program
SWAT	Soil Water Assessment Tool
TLB CRFP	Top Level Budget Climate Resilience Focal Point(United Kingdom)
UA	University of Arizona
UKMoD	United Kingdom Ministry of Defence
USFS	United States Forest Service (Department of Agriculture)

Table of Contents

Keywords

Adaptation
Baseline sensitivity
Climate change
Climate exposure
Climate services
Extreme events
Fire risk
Fire severity
Risk assessment
Risk management
Scenario based decision support
Stakeholder engagement
Training

List of Figures

List of Tables

Page Intentionally Left Blank

1. Objective and Overview of the Report

This report summarizes the results and conclusions from RC-2232 “Climate Change Impacts and Adaptation on Southwestern DoD Facilities,” a project awarded by the Strategic Environmental Research and Development Program (SERDP) associated with the Resource Conservation and Climate Change Statement of Need “Climate Change Impacts to Department of Defense Installations” (RCSON 12-02). The technical objectives of the project were to develop approaches for: assessing climate-related risk, identifying promising approaches for making climate adaptation part of DoD operational practice, developing guidance for climate decision-making best practices in the face of uncertainties, identifying opportunities for the provision of climate services, and assessing the prospects for bridging the gap between short-term decisions in the current climate context and prospects for decisions related to changing conditions at decade-to-century time horizons of projected climate change. We interacted with DoD managers and staff in risk assessment workshops and case-study pilots at four installations in the Southwest, through highly interactive and participatory processes. We also conducted interviews and convened workshops with personnel at multiple levels in the DoD hierarchy, in order to identify gaps, needs, and opportunities for infusing climate adaptation thinking and practice into DoD operations, and to evaluate promising approaches to climate services, that mesh with military culture, leadership, and practice.

In the first section of this report, we describe our research methods, findings, and conclusions. In Section 2, we provide an overview of the issues that our research addressed, and how examination of these issues relates to DoD practices. In Section 3, we discuss the methods that we used in our climate risk assessment and adaptation case studies, conducted at Fort Huachuca (U.S. Army), Barry M. Goldwater Range East (U.S. Air Force), Barry M. Goldwater Range West (U.S. Marines), and Naval Base Coronado (U.S. Navy), as well as our approaches and methods for evaluating current and future risk of wildfire and post-fire flood risk, social science approaches used to understand and evaluate best practices for incorporating climate adaptation into DoD decision making, and methods used in our assessment of the climate services needed support DoD adaptation decisions and to move research conducted in collaboration with DoD installations into operational practice. In Section 4, we describe the results of our case studies, best practice assessments, and evaluation of alternative approaches to climate services to meet DoD decision making needs. In Section 5, we present conclusions regarding installation-level climate information needs, risk assessment, communication and engagement strategies needed for successful climate adaptation initiatives, the roles of leadership, institutions, partnership, and military culture in mediating successful adaptation, and prospects for the provision of climate services to support DoD adaptation efforts. We conclude with a listing of literature (Section 6) and several Appendices that chronicle our research and provide technical details.

2. Background

2.1 Climate change challenges

The US Department of Defense (DoD) faces emerging climate risks and challenges across its portfolio of responsibilities: as a major land manager, as operator of hundreds of installations, and in its core mission to protect global security. While the 2014 Climate Adaptation Roadmap (U.S. DoD 2014) and DoD Directive 4715.21 (U.S. DoD 2016) establish the motivation and responsibilities for development and implementation of climate change adaptation plans, the Department lacks specific guidance on methods and best practices, and the array of support services needed to establish adaptation and climate time-scale thinking as part of standard operating procedures. This report details the methods, findings, and conclusions from the DoD Strategic Environmental Research and Development Program (SERDP) project, Climate Change Impacts and Adaptation on Southwestern DoD Facilities. In collaboration with four military installations in the Southwest, we tested a risk assessment method, climate-driven wildland fire risk assessment tools, and techniques for stimulating useful dialogues on climate change adaptation and communicating climate-related risks; evaluated best practices from industry and international departments of defense; and assessed barriers to and opportunities for implementing adaptation plans and support services. The key objectives of the study were to develop and pilot and approach for climate risk assessment, evaluate climate adaptation best practices, and evaluate approaches and needs for climate services to support adaptation planning that is compatible with DoD decision-making needs and processes (Garfin et al. 2017).

2.2 Climate change and the Department of Defense

The United States Department of Defense (DoD) is the largest military organization in the world. DoD dominates the budget of the U.S. government ($590 billion in the 2014 and 2015 DoD Financial Summary Tables), larger than the GDP of many countries. The DoD executes the strategic and tactical objectives of the U.S. across the globe. DoD is the largest U.S. government agency, employing over two million active duty military personnel, National Guard members and reservists, as well as over 700,000 civilian personnel. DoD is also the largest single energy consumer in the U.S. (Lyle 2012). In 2014, the DoD publicly released its Climate Change Adaptation Roadmap, as part of a longer-term effort to adapt to climate change impacts, reduce greenhouse gas (GHG) emissions, and recognize the potential geopolitical consequences of climate change (U.S. DoD 2014). In 2016, DoD Directive 4715.21 further articulated climate adaption as a Department-wide priority and established responsibilities for implementation (U.S. DoD 2016).

Much of the recent military interest in climate adaptation comes from top-down institutional policy, including DoD leadership and the White House. Former President George W. Bush's 2008 Defense Authorization Act and President Barack Obama's 2009 Executive Order 13514 (HR 2007; Obama 2009) required federal agencies to begin including climate considerations in their protocols for sustainability and security. The 2010 Quadrennial Defense Review recommended that climate change adaptation considerations be included in strategies and operations across the Armed Services (DoD 2010); this was reiterated in 2014 and in the 2016 Directive aimed at mobilizing climate preparedness within the Department (DoD 2016). Four

Obama Executive Orders and the President's Climate Action Plan (Obama 2013) addressed federal responsibilities in managing climate change; for example, his 2013 Executive Order 13653 'Preparing the United States for the impacts of climate change' directs federal agencies to develop and implement strategies to evaluate and address the most significant climate change related risks (Obama 2013). In addition to national policy, some base commanders and their staff are motivated to engage in adaptation and resilience efforts after witnessing first-hand the effects of climate-related impacts on their installations and assets.

The DoD 2014 Roadmap explicitly acknowledges the potential impacts of climate change on the agency's mission, noting for instance that "climate-related effects are already being observed at installations throughout the U.S. and overseas and affect many of the Department's activities and decisions related to future operating environments, military readiness, stationing, environmental compliance and stewardship, and infrastructure planning and maintenance." The three main goals of the Roadmap are to: (1) identify and assess the effects of climate change on the DoD; (2) integrate climate change considerations across the DoD and manage associated risks; and (3) collaborate with internal and external stakeholders on climate change challenges (DoD 2014). Nonetheless, implementation of the 2014 Roadmap is an enormous challenge. A Government Accountability Office (GAO) assessment of DoD's actions to adapt its U.S. infrastructure to climate change challenges concluded that although the DoD has begun conducting vulnerability assessments of climate change impacts on its installations, a lack of planning may hamper completion of its efforts (GAO 2014).

2.3 Past research: State of the science at the beginning of the project

Our five major technical objectives are interconnected, due to the spatial and temporal pervasiveness of climate and weather impacts on DoD installations and activities, connections between affected infrastructure, resource, and risk management systems, and the support systems needed to address climate-related decisions. This brief literature-based review of the state of the science approaches each objective separately, but we have shown some integration where appropriate.

Climate risk assessment. At the start of the project, much of the state of the science with respect to climate risk assessment was focused on methods established by the Intergovernmental Panel on Climate Change (e.g., Schneider et al. 2007; IPCC 2014a), and was derived, in part, from the natural hazards and disaster risk reduction literature (e.g., UNISDR, 2005), from literature and practice on drought planning (e.g., Wilhite et al. 2000a, 2000b, 2005), and from ideas about adaptive management (e.g., NRC 2004; Williams et al. 2009). Key aspects of these methods include an emphasis on preparedness through: conducting assessments, inventorying resources and groups at risk (e.g., vulnerability assessment), seeking stakeholder participation, developing early warning through indicators, monitoring, and integration of new research, integrating best available science with policy or operational practices, strengthening institutions, developing capacity through dialogue, coordination and knowledge exchange, improving capabilities through education, and reducing underlying risk factors. While some climate risk assessment methods emphasized analysis of the combination of likelihood and consequence, others noted that probabilistic estimates may be confounded by high uncertainties—some of which are due to multiple interacting factors leading to a potential cascade of impacts. Thus, focusing on

imminent risks that are likely to become more intractable provides grounding for a usable risk assessment approach (e.g, UNDP 2009). Our starting point was a risk-based framework originally developed by the UK Climate Impacts Programme (UKCIP) and the UK Environment Agency: "Risk and Uncertainty Framework" (Willows and Connell 2003).

Integrating climate adaptation with DoD operational practice. At the start of the project, much of the state of the practice with respect to integrating climate science into adaptation and operational practices suggested multiple possible approaches. Some guidance proposed the development of standalone plans (e.g., Snover et al. 2007, National Park Service 2010), in which it was assumed that a parallel set of programs and policies, containing adaptation strategies, would operate in conjunction with existing policies and practices; undoubtedly, this practice of separating climate change adaptation from day-to-day decision-making would be necessary in some situations. Also, developing a standalone adaptation plan could potentially ensure better integration among elements of climate change planning (e.g. more consistent assumptions about future conditions), which would, presumably, result in a lower likelihood of mal-adaptations, or unintended consequences of implementing adaptation strategies. In contrast, a growing body of literature supported (and continues to support) *mainstreaming*, an approach whereby consideration of climate change, and needed contingencies, are incorporated into existing decision making (e.g., Klein et al. 2005; National Research Council 2010; Smith et al. 2010). A risk of mainstreaming is that adaptation strategies may be adopted piecemeal and/or not receive sufficient attention to respond to the associated risks; lacking the holistic framework of a standalone plan, some strategies may work at cross-purposes with others, leading to maladaptive approaches to addressing climate risks.

Climate decision-making under uncertainty – best practices. At the outset of the project, some literature indicated that the communication and/or quantification of uncertainty associated with climate science was too great of a barrier for it to be useful for decision making (e.g., Dilling and Lemos 2011; Kerr 2011). This implies that timely and reliable science-based information and communication of uncertainties, extremes, tipping points, and the limits to predictability, as well as assessments of confidence in forecasts and projections are inadequate to allow the science community to help society prepare for changing climate conditions. Engagement and knowledge exchange are needed in the context of climate change applications for decision support. However, there is an increasing tension between model complexity and decision makers' needs for simplicity (Meyer 2012).

Prior to our project, it had already been documented that interaction and knowledge exchange between scientists and practitioners may help bridge gaps between different kinds of knowledge, such as explicit knowledge (e.g., facts and figures) and experiential or contextual knowledge, and increase openness to new knowledge and novel options (Weber 2006). Planning processes, such as the use of scenario planning in risk assessment (e.g., Mahmoud et al. 2009; Weeks et al. 2011), had also been documented as a way to help practitioners to better prepare for multiple uncertainties—including those related to future climate (e.g., uncertainties related to changes in population, economics, politics, regulations, public support) (Means et al. 2010).

Providing climate services in support of adaptation. Climate change adaptation planning, based in part on the principles of adaptive management (e.g., Williams et al. 2009), is an iterative process, which requires ongoing monitoring and revision of approaches in order to incorporate insights from new observations and new scientific research and information. Typically, organizations with risks related to exposure to weather systems and singular weather events (e.g., hurricanes) have sufficient support for short-term—one hour to one week—decision making, but lack expertise in climatology, which encompasses decision time scales of seasons to decades (Hewitt et al. 2012). As indicated by literature and research available at the outset of this project, climate time-scale decisions require multiple types of support, ranging from long-term observations and data quality control, to forecasts and modeling, research, decision-support tools, and translational services—in order to make sense of forecast and climate projection uncertainties, emerging issues, and climate-informed planning processes (e.g., Jacobs et al. 2005; Miles et al. 2006; DeGaetano et al. 2010; Hewitt et al. 2012). By co-developing communication ground rules and protocols, and encouraging two-way communication through iterative dialogue, participants in adaptation planning processes can avoid miscommunication and build relationships that can support mutual understanding (Lemos and Morehouse 2005). The application of these approaches forms a foundation for identifying and discussing risks and uncertainties, evaluating the appropriateness of information to be used in the process, and increasing the fit (i.e., how users perceive climate information meets their needs), and the uptake of scientific information to inform decisions (Kirchhoff et al. 2013).

Connecting imminent risk with risks associated with projected long-term climate changes. Based on the experience of slow onset hazards, such as drought, there is a danger that only focusing on the short-term without weighing long-term benefits of loss-reduction measures, or strongly discounting low-probability, high impact events, can result in severe consequences (National Research Council 2010). Short-term solutions can reduce incentives to explore longer-term options, which may initially be more costly (National Research Council 2010). Moreover, the drought planning literature is rife with examples of reactive or crisis drought management, in contrast to proactive drought preparedness planning (Wilhite et al. 2000b). Nevertheless, previous research suggests that current or recent experience of climate impacts or imminent risks enhances people's willingness to prepare for longer-term risks (e.g., Fussel 2007; Wilby and Dessai 2010). There is a certain "seeing is believing" aspect of communicating the connection between imminent challenges and potentially amplified long-term challenges, which is encapsulated in the adage "never let a good crisis go to waste." Consequently, there can substantial traction for connecting climate change adaptation planning to imminent risk issues such as hurricanes, storm surges, and wildfires.

2.4 RC-2232 Research to meet the challenge

In support of managing climate risks, DoD funds research and development through the Strategic Environmental Research and Development Program (SERDP). A central goal of this effort is "to improve our ability to assess the potential impacts to DoD permanent installations due to climate change and to facilitate appropriate adaptive responses" (SERDP 2010). In response to SERDP Statement of Need RCSON-12-02, our research team investigated unique opportunities and challenges faced by the DoD as it attempts to incorporate climate change adaptation planning throughout its vast mission space. The goal of this work was to place DoD's challenges in the context of best practices currently being adopted by a growing global community of climate adaptation scientists working with a wide range of stakeholders and organizations. The project responded to the following specific objectives and needs articulated in RCSON-12-02:

1. Identify the type and value of climate-related information, including information on associated physical effects that result from climate forcing (e.g., changes in flood and fire regimes), and are needed by DoD natural and built infrastructure planners and managers to assess future climate change risks and vulnerabilities.

We tested methods to assess current and future climate-related impacts and risks, including the data, information, and climate services research and information translation support needed by natural resource management and built infrastructure planning and management personnel, to assess climate change risks and vulnerabilities.

2. Identify, enhance, or develop tools and methodologies that enable the generation of such information at the required spatial and temporal scales and its associated uncertainties that are of value to the preceding end-users.

As a demonstration of proof of concept for supporting DoD decision-makers more broadly, we tested readily accessible and publicly available data and decision tools and methods to generate information on climate-driven wildland fire and post-fire flooding risks, and associated uncertainties.

3. Develop pilots to assess approaches to climate change risk assessment and decision-support strategies that are resilient in the light of the uncertainties.

We developed installation-focused pilot projects to assess a participatory approach to climate change risk and vulnerability assessment, and to co-develop, with installation personnel, strategies that are resilient in light of uncertainties. We developed a science-based decision support process, and co-developed strategies for management of wildland fire risk. We also convened a workshop of related SERDP climate change projects, and synthesized expert advice on risk assessment, decision-support, uncertainties, and the climate services needed to support decisions.

4. Types of weather-related decisions that DoD natural and built infrastructure planners and managers already make, how weather affects those decisions, and the temporal and spatial nature of those decisions.

We investigated and catalogued weather-related decisions made by planners and managers at four installations in the Southwest, and examined how weather affects those decisions.

5. Development and use of decision-support strategies and analytic methods that support adaptive strategies whose performance is relatively insensitive to poorly characterized uncertainties.

We developed a science-based decision support process which included the co-development of strategies, along with installation resource management personnel, for management of wildland fire risk in the face of uncertainties. We assessed approaches used by analogous entities, such as international departments of defense, heavy industries, and multi-faceted state and city governments, and summarized best practices currently being adopted by this array of climate-sensitive entities.

The results of our project can be used by SERDP and the DoD to inform risk assessment methods, and approaches for developing installation-specific and DoD-wide capacities to provide climate services to encourage adaptive decisions in the face of a changing climate. Our results can also inform the wider literature on risk assessment, climate adaptation planning and process, and climate services in support of adaptation.

3. Materials and Methods

Introduction

This section focuses on the many approaches that we used to answer the research questions posed in our original and revised proposals (the revised proposal was submitted to SERDP as a White Paper, in August 2015, with revisions in October 2015). There are four broad categories of methods, as follows: (1) communication materials and methods used to convey information about the climate drivers that provide the physical exposure to climate change at each Southwest installation in our study; (2) participatory stakeholder engagement methods that we used, in a workshop context, to assess climate change risks at each installation, and to identify and prioritize adaptation strategies to address those risks; (3) biophysical science methods for assessing current and projecting future risks related to key climate exposures; (4) interview, focus group, and literature review methods for garnering expert insights on barriers and opportunities to implementing climate adaptation at DoD installations, best practices for climate-related decision-making in the face of uncertainties, and the provision of climate services to support DoD climate change adaptation at multiple scales.

The sum total of the project methods shows a path forward for increased capacity to incorporate climate change adaptation into other planning and risk management processes. Our results indicate that operational changes in response to a specific climate risk promote consideration of climate change risk into associated planning and help to stimulate incorporation of climate change risk throughout the planning process. Combining site specific scenario based initiatives with collaborative and cross project workshops, interviews, and consideration of adaptive practices sectors has yielded a holistic approach that has broader impacts than working solely with a simple science-based or technology-centered approach.

By strategically working with installation personnel our project team was able to co-identify current and future risks and foster dialogue for mainstreaming site-specific climate change projections and scenarios into future decision making strategies. This led to identification of specific climate-related concerns that could are currently affecting base operations, or will in the near term.

Opportunities emerging from this methodology include an increased focus on science-based solutions for addressing site specific issues, capacity building of base personnel, and the potential to include climate change adaptation strategies in future planning and risk management processes. Specific opportunities for continued and active engagement with installation and natural resource personnel have also developed through the co-identification of risks associated with fire, flood and drought.

Our approach addresses the following questions:

- *What are the climate challenges that DoD managers face now and are likely to face?*
- *What are the data needs of DoD managers with regard to their operational goals and infrastructure planning in adapting to climate change?*
- *What are the risks and uncertainties with regard to climate change impacts experienced*

on DoD facilities?

- *What are the currently available climate and ecological data and information products available for meeting the identified DoD needs, e.g., related to weather, hydrology, vegetation, and fire regimes, and what can be done to ensure the most efficient and effective use by DoD managers?*
- *What modifications to current data and information products can be made to improve the match between state-of-the-art climate models and DoD needs?*
- *How can DoD managers assess and manage the risks of climate change through a robust and replicable approach, given the unknowns and uncertainties of existing information*

In the following subsections we specifically describe our methods in two parts; subsections 3.1 through 3.5 detail the assessment and identification of climate change risks at specific installations, and in subsections 3.6-3.8 we outline methods used to a) connect current and future risks, b) investigate adaptive strategies through analysis of other sectors and c) highlight institutional barriers and opportunities. The overview of our methodology is illustrated in Figure 1.

Objectives	Methods	Sections & Subsections
• **A)** ***Develop*** *and pilot-test approaches for climate risk assessment*	• **A) Communication materials and methods** used to convey information about the climate drivers that provide the physical exposure to climate change at each Southwest installation in our study; **Participatory stakeholder engagement methods** that we used, in a workshop context, to assess climate change risks at each installation, and to identify and prioritize adaptation strategies to address those risks	• **A) 3.1, 3.6**
• **B)** ***Evaluate*** *climate adaptation best practices in a series of case studies*	• **B) Interview, focus group, and literature review methods** for garnering expert insights on barriers and opportunities to implementing climate adaptation at DoD installations, and best practices for climate-related decision-making in the face of uncertainties	• **B) 3.6, 3.7, 3.8**
• **C)** ***Evaluate approaches and needs for climate services*** *to support adaptation planning compatible with DoD decision-making needs and processes*	• **C)Biophysical science methods** for assessing current and projecting future risks related to key climate exposures; Interview, focus group, and literature review methods for garnering expert insights on the provision of climate services to support DoD climate change adaptation at multiple scales	• **C) 3.2, 3.3, 3.4, 3.5, 3.6, 3.8**

Figure 1. Overview of Project RC2232 objectives and methods

3.1. Project-wide methods for assessing climate change risk and identifying and prioritizing climate adaptation strategies

3. 1. 1. Studies to inform DoD efforts to adapt to a changing climate

We initiated our interactions with each installation through a designated DoD service branch liaison or through our contact network. The liaisons facilitated meetings with base personnel, representing a range of installation activities, through which our team started a conversation about the project and the potential benefits of engagement, as well as the range of potential climate-related issues. Because we were aware that there is often a mismatch between the information produced by scientists and the type and format needed by decision-makers, we deliberately designed our approach to build trusted relationships with base personnel, in order to assess their concerns and needs, gain understanding of their decision context (including existing practices, procedures and constraints), iteratively exchange knowledge about the ability of the scientific community to provide timely and useful information that is usable given decision-makers' needs and situation, and exchange knowledge about decision-makers' decision criteria and local knowledge in the area of concern (e.g., Jacobs et al. 2005; Lemos and Morehouse 2005; National Research Council 2009; National Research Council 2010; Dilling and Lemos 2011; Ferguson et al. 2014; Meadow et al. 2015). We designed our climate adaptation interactions with DoD personnel, based on strategies and methods recommended by the aforementioned literature, and a National Research Council report (2009), which recommended using the approach of "deliberation with analysis" when feasible. Deliberation with analysis incorporates the following practices and characteristics:

- Inclusive participation;
- Transparency and open communication;
- A collaborative definition of the problem and objectives;
- Working with experts to generate and interpret decision-relevant information; and
- Revisiting objectives and choices based on that information.

Such methods help develop trust between technical experts, stakeholders, and decision-makers, and effective engagement, leading to enhanced integration of science in decisions. By co-developing communication ground rules and protocols, and encouraging two-way communication through iterative dialogue, participants in adaptation planning processes can avoid miscommunication and resentment (National Research Council 2010), and build relationships that can support mutual understanding. Most important for our work, in-person interactions formed a foundation for identifying and discussing mission objectives, measures of success, risks and uncertainties, barriers and opportunities for actions, and research, data, and information needs and gaps. The process improves the fit (i.e., how users perceive climate information meets their needs), and the uptake of scientific information to inform decisions (Kirchhoff et al. 2013).

The aforementioned methods to establish knowledge exchange are especially needed in the context of climate change applications, where there is tension between model complexity and decision makers' needs for simplicity (Meyer 2012). Finally, effective interaction and knowledge exchange may help bridge gaps between different kinds of knowledge, such as explicit

knowledge (e.g., facts and Figures) and experiential or contextual knowledge, and increase openness to new knowledge and novel options (Weber 2006).

We followed the initial meetings with workshops and work sessions that included a wider range of installation personnel, and where appropriate, representatives from neighboring organizations such as NGOs, tribes, state and federal agencies with jurisdiction over adjoining lands. Our risk-based assessment method (described below – Willows and Connell 2003) was designed to connect immediate risks with future threats; similar approaches have been endorsed by a variety of national and international climate assessment processes (e.g., NRC 2010; IPCC 2014a; Melillo et al. 2014). These workshops provided an overview of regional assessments of climate impacts and projections (Garfin et al. 2014) along with new knowledge relevant to the installation; identified installation personnel's primary roles, responsibilities, key objectives and success criteria; and reviewed potential risks for different mission areas.

The rationale for this approach was to translate perceived climate-related risks into a language and framework already being used for non-climate-related risks to operations in other contexts—i.e., *mainstreaming*. For two of the installations, NBC and FTH, we conducted specific research and analysis of climate-related risks, to illustrate how defense installations can approach local climate adaptation in the context of ongoing decision-processes.

3.1.2. Conveying exposure to climate change, and conveying data and information

Climate communication. To convey the potential exposure to climate change in accordance with our risk assessment method, we followed some fundamental principles of climate change and risk communication. First, we used non-persuasive communication (Fischhoff 2007) to frame our discussions; our goal was to invite installation personnel and workshop participants into a discussion of climate and weather and their impacts on the installation and its mission, rather than to convince participants of any particular viewpoint. Thus, we began each workshop and other interaction with discussions about recent extreme weather- or climate-related events and impacts on the installation and its mission; this framing helped ground the discussion in issues of local scale (Bostrom et al. 2013), and immediate experience, interest and urgency (Slovic 2000; Slovic et al. 2004; Weber 2006). Anchoring the initial conversations in historic and recent time frames set the stage for our team to present future climate projections and to ground discussions of future impacts in terms of avoiding future losses, which the literature suggests is a more promising frame than focusing on future gains (e.g., CRED 2009).

Authoritative information. To the extent possible, we used climate information and graphics from recent and authoritative sources, such as the U.S. National Climate Assessment (Melillo et al. 2014). For workshop interactions and in background research used to describe historical climate extremes and trends, we used a combination of (a) gridded datasets for the conterminous U. S. (Daly et al. 2008), and (b) information derived from recent literature pertaining to the climate of the region (e.g., Hoerling et al. 2013; Kunkel et al. 2013; Vose et al. 2014; Walsh et al. 2014). The latter used slightly different data, such as individual meteorological stations (Hoerling et al. 2013) and gridded datasets based on the station data (Walsh et al. 2014).

When presenting information about future climate, and in background research used to describe projected climate extremes and trends, we used a combination of (a) pre-existing multi-model projections, based on recent literature pertaining to the future climate of the region (e.g., Cayan et al. 2013; Walsh et al. 2014), and (b) installation-specific projections, based on authoritative and easy-to-access downscaled climate projection data archives (e.g., Abatzoglou 2013; Maurer et al. 2007). For climate impacts research that used vegetation, fire, and hydrological process models, we used future gridded regional climate projections from existing databases (e.g., Abatzoglou 2013; MACA 2014). At the outset of the project, we based our future scenarios on projections from the National Climate Assessment (Walsh et al. 2014) and the Assessment of Climate Change in the Southwest United States (Garfin et al. 2013), respectively. Synthesis reports like these are inherently cautious in the information that they provide, due to their reliance on previously published, peer-reviewed literature, and on a process that favors consensus among many report authors and reviewers. We relied upon these sources because they have been well-vetted, are broadly perceived as credible and authoritative, and provide timely and easy-to-access data and analyses suitable as a point of departure for discussions of adaptation to potential climate changes.

Both sources of information use statistically downscaled climate projections, based on the World Climate Research Programme's Coupled Model Intercomparison Project, phase 3 (CMIP3) multi-model dataset (Meehl et al. 2007), as well as dynamically downscaled projections (Mearns et al. 2013). These sources use two future global greenhouse gas (GHG) emissions scenarios, A2 (continued high rates of GHG emissions) and B1 (substantially reduced rates of GHG emissions), in order to contrast divergent possible futures, which is important for assessment dialogues. In later stages of our research, we incorporated statistically downscaled CMIP5 projections, with an RCP 8.5 emissions scenario, (a) to demonstrate a wider spectrum of uncertainty, and (b) as applied to modeling future vegetation, fire, and flood risks, such as we have done at Fort Huachuca. We acknowledge the limitations of both statistical and dynamically downscaled data (see RC-2232 data white paper – Garfin 2016; Kotamarthi et al. 2016) and, as mentioned below, our discussions with personnel and workshop participants acknowledged the uncertainty associated with GCM projections of future climate.

The data used to inform process model projections. In our non-workshop interactions, such as when we developed vegetation and fire change projections for analyses of interest to installations, we selected subsets of climate model projections, following guidelines from the scientific literature (e.g., Brekke et al 2008; Pierce et al. 2009; Sheffield et al. 2013). In the southwest U.S., one of the greatest challenges in projecting climate is accurate representation of the North American Monsoon (NAM), which is responsible for more than half of annual precipitation in parts of northern Mexico, southern Arizona and New Mexico. Careful selection of GCMs that appropriately model the climate feature of interest (in this case summer precipitation) at the regional scale, when compared with historical observations, reduces the risk of using low-quality inputs to downscaling. In a recent evaluation of CMIP5 GCMs, the CanESM2, HadCM3, and HadGEM2-ES GCMs were found to have the lowest error rates, respectively, for characterizing the NAM from 1975-2005 (Sheffield et al. 2013). Thus, we used this GCM subset as input for downscaling projections for the Southwest, to be used in our process model studies for Fort Huachuca (U.S. Army), Arizona.

Process model output: downscaling. At Fort Huachuca, in southeastern Arizona, the high topographic complexity, relatively high density of weather stations available for generation of transfer functions, relatively short time horizon used for climate change planning, and need for daily weather inputs at high spatial resolution led us to select a publicly available statistically downscaled regional climate product, with 4 km resolution. Moreover, because our main interest was the projection of future fire risk, we sought a dataset with characteristics appropriate for this application. We used the Multivariate Adaptive Constructed Analogs (MACA) statistically downscaled product (Abatzoglou and Brown 2012), available for the conterminous U.S. (MACA 2014). To expedite the modeling process for our pilot modeling studies for Fort Huachuca, we selected the output from a single GCM (O'Connor et al. 2015; O'Connor et al. 2016a). Downscaling was based on the CanESM2 GCM, one of a small group of CMIP5 models considered capable of representing the summer monsoon system of the Southwest (Sheffield et al 2013). To capture a "worst case" scenario, we selected the IPCC Representative Concentration Pathway (RCP) with a radiative forcing of 8.5 W/m^2 in the year 2100 (i.e., RCP 8.5; van Vuuren et al. 2011). This pathway represents the radiative forcing effect of no proactive reduction of global greenhouse gas emissions (i.e., global emissions policy can be characterized as "business as usual") and may be a conservative estimate of actual greenhouse gas concentrations later in the century. [N.B.: Representative Concentration Pathways (RCPs) are trajectories of concentrations of greenhouse gases and pollutants resulting from human activities, including changes in land use. RCPs provide a quantitative description of concentrations of the climate change pollutants in the atmosphere over time, as well as their radiative forcing in the year 2100, expressed in units of watts per square meter (van Vuuren et al. 2011; Bjørnæs 2013). Radiative forcing, expressed in units of watts per square meter, is the additional energy taken up by the Earth system due to the enhanced greenhouse effect. It can be defined as the difference in the balance of energy that enters the Earth's atmosphere (e.g., from the sun) and the amount that is returned to space (e.g., bounced back off of clouds, or re-radiated from the Earth's surface) compared to the pre-industrial balance of energy (van Vuuren et al. 2011; Bjørnæs 2013).]

Communicating uncertainty. In working with land managers at installations in the Southwest, we acknowledged financial and other limitations of installations to conduct extensive treatments, modifications, and adaptations to vegetation and at-risk infrastructure. We emphasized the need to be proactive, because treatments may take more than a decade to implement. In our discussions, we articulated the need to consider the multiple dimensions of uncertainty (e.g, political, legal, social, biophysical), the rapid rates of change currently projected, and the possibility of abrupt, landscape-scale change (O'Connor et al. 2015; 2016a). With respect to climate model projection uncertainties, we explicitly mentioned a range of issues, such as: (a) trade-offs in the robustness of the projections related to the number of models and model runs used, (b) increases in uncertainty at shorter time steps, (c) increases in uncertainty at smaller spatial scales, (d) uncertainties in future projections related to assumptions about greenhouse gas emission trajectories, and (e) the likelihood that uncertainties related to climate model projections will change with the increased complexity and improvements in model spatial resolution in future generations of climate models. Thus, we emphasized that our modeling results are not forecasts and should be interpreted with caution.

The use of risk management framing (see below) allowed us to explicitly describe, even if in qualitative terms, the uncertainty dimensions of potential climate-related impacts. Moreover,

through debriefings with installation staff and leadership, we explicitly connected short-term decisions and strategies to future risk (O'Connor et al. 2016b). In the cases for which we have used GCM projections as inputs to vegetation, fire, and hydrologic process models, we used modeling of worst-case scenarios as a point of departure for discussions to elicit interest in using adaptation strategies to prepare for potential challenges. Risk-based management justified a focus on being prepared for a range of possible futures, including worst-case events (e.g., Wilby and Dessai 2010).

3.1.3 Tier 1 Methods for assessing climate change risks, and for identifying and prioritizing climate adaptation strategies

3.1.3.1 Key Concepts

The language of risk is frequently used in climate change assessments, as exemplified in the third U.S. National Climate Assessment (Melillo et. al, 2014) and the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report, which places the concept of risk firmly at the center, stating that "risk management provides a useful framework for most climate change decision making" (IPCC 2014a). However, because the issue concerns both current climate variability and future climate change, there is an inevitable degree of uncertainty about the timing, pace, and severity of possible impacts, as well as the options for managing and avoiding them. For our interactions with installations in the U.S. Southwest, we used the following risk and uncertainty definitions and meanings:

- **Risk**: The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values (IPCC 2014b). Risk is often represented as probability of occurrence (likelihood) of hazardous events or trends multiplied by the impacts (consequence) if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard are shown in Figure 2 (IPCC 2014b).

- **Uncertainty**: A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, or uncertain projections of human behavior. Uncertainty can therefore be represented by quantitative measures (e.g., a probability density function) or by qualitative statements (e.g., reflecting the judgment of a team of experts) (IPCC 2014b).

- **Likelihood/probability**: the likelihood / probability component of risk is a general concept relating to the chance of an event occurring. This can be expressed as a quantitative probability (e.g., >90%) or as a qualitative likelihood (e.g., "Very likely").

- **Consequence (impact):** The end result or effect on society, the economy or environment caused by an event or action (e.g., economic losses, loss of life). Consequences may be beneficial or detrimental. This may be expressed qualitatively (high, medium, low) or quantitatively (monetary value, number of people affected, etc.) (Defra 2012).

- **Vulnerability:** The propensity or predisposition to be adversely affected. Vulnerability

encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC 2014b).

- **Exposure:** The presence of people, livelihoods, species or ecosystems, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected (IPCC 2014b).

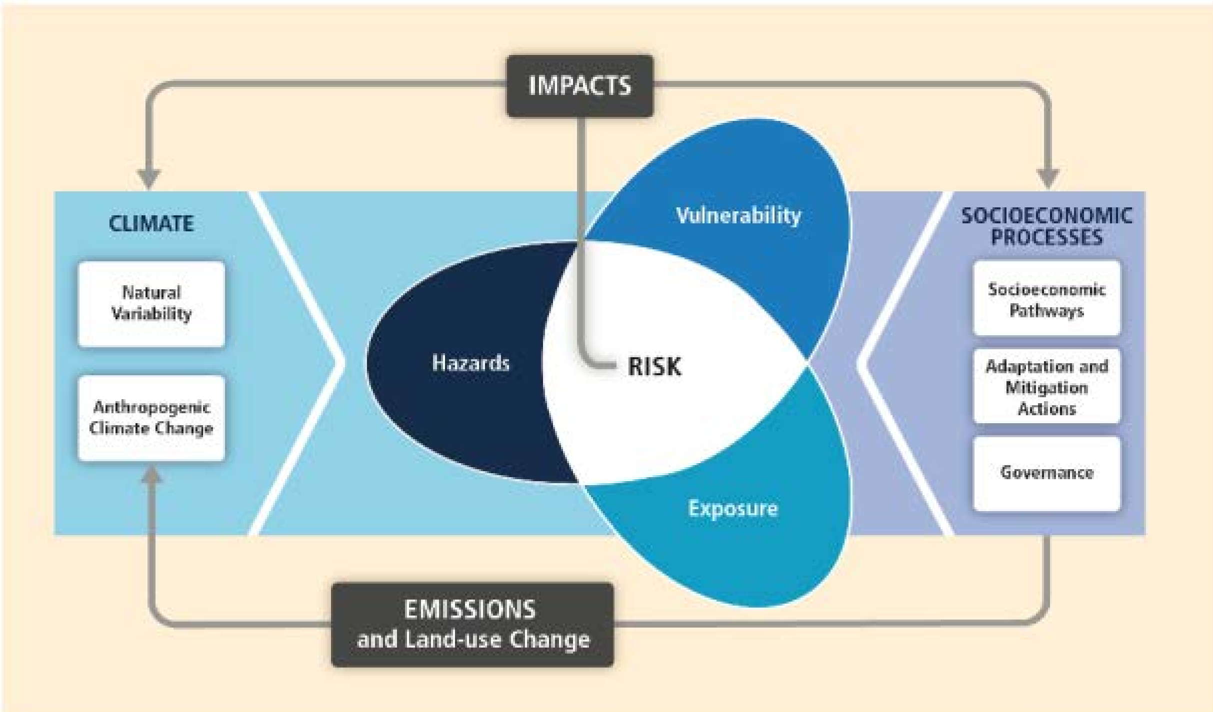


Figure 2. Schematic of the interaction among the physical climate system, exposure, and vulnerability producing risk from IPCC 2014.

Risks are a product of a complex interaction between physical hazards associated with climate change and climate variability on the one hand, and the vulnerability of a society or a social-ecological system and its exposure to climate-related hazards on the other. Vulnerability and exposure are largely the result of socio-economic development pathways and societal conditions (although changing hazard patterns also play a role). Changes in both the climate system (left side) and development processes (right side) are key drivers of the different core components (vulnerability, exposure, and hazards) that constitute risk (IPCC 2014a).

3.1.3.2 Our risk assessment framework and approach

We based our climate change risk assessments on a risk-based framework originally developed by the UK Climate Impacts Programme (UKCIP) and the UK Environment Agency: "Risk and Uncertainty Framework" (Willows and Connell 2003; Figure 3). This framework is acknowledged by United Nations Development Programme as one that uniquely deals with uncertainties; it has been used by the World Bank, the IPCC and other organizations in public and private sector contexts. Moreover, it was used as the basis UK Climate Change Risk

Assessments. The IPCC has embraced this approach forward and presented a modified version in the Fifth Assessment Report, as shown in Figure 4.

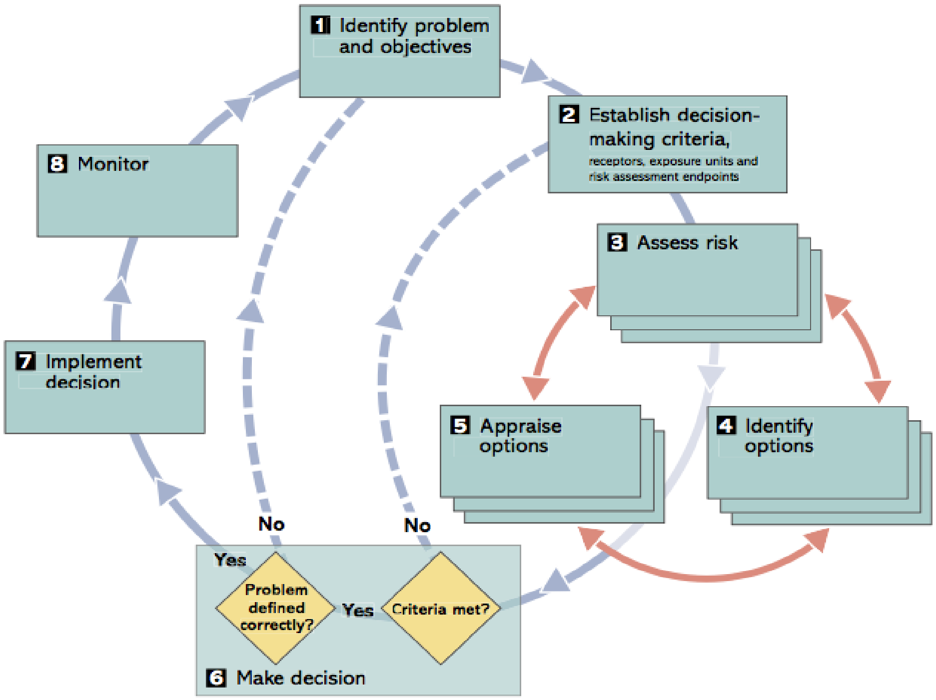


Figure 3. Decision-making framework for addressing climate change from IPCC

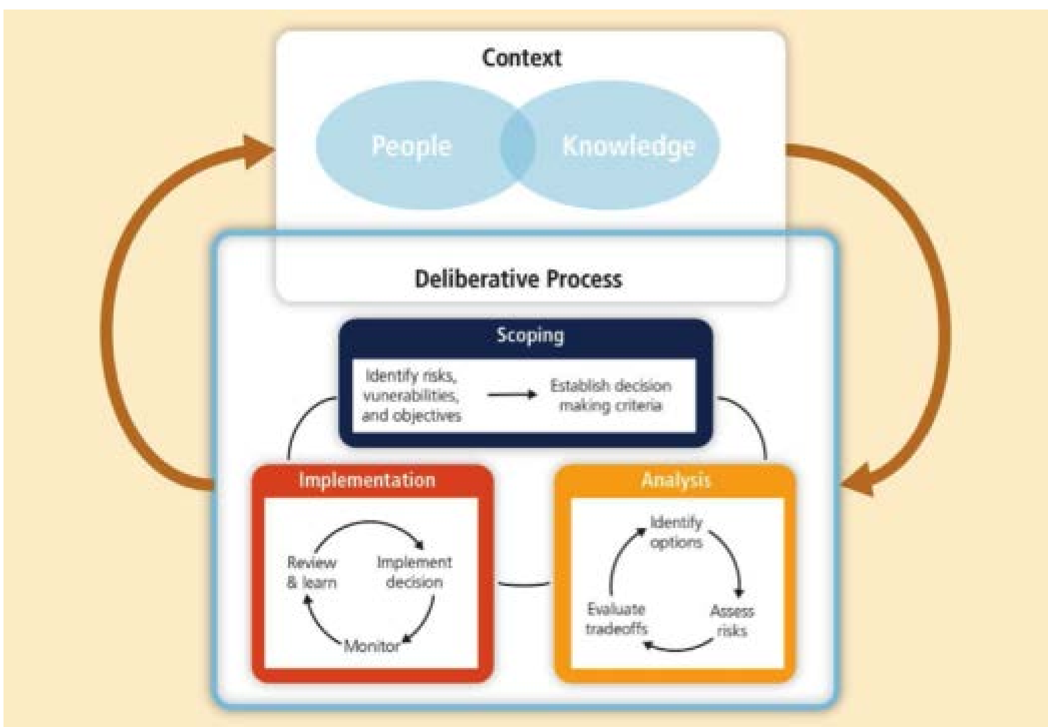


Figure 4. IPCC (2014a) framework (adapted from Willows and Connell 2003)

Our framework includes the eight stages illustrated in Figure 3. Our interactions with NBC and BMGR were limited to Stages 1 to 3, as outlined below.

- **Stage 1 –** Identify objectives: This stage involves understanding the objectives/mission of individual installations, and establishing the reasons for inclusion of climate information into decisions. This includes an understanding of existing vulnerabilities to climate variability and future risks from a changing climate, the relative importance of climate change as a driver of risk, and which personnel need to be involved in climate risk discussions. [This is comparable to the first step in the "Scoping Phase" in the IPCC Framework – Figure 4].

- **Stage 2 –** Establish decision-making criteria: This stage involves defining the risk criteria, exposure units, thresholds, receptors and performance criteria, together with determining the process by which risks will be evaluated—including how the results will be used, and identifying stakeholders (e.g., representatives of land holdings just beyond the fence line) who need to be consulted about the climate change risk assessment. [This is identical to the second step in the "Scoping Phase" in the IPCC Framework – Figure 4].

- **Stage 3 –** Assess risks: Climate change risks are assessed, utilizing three central steps, which consider the three core components of risk depicted in Figure 2 [This is consistent with the "Analysis Phase" in the IPCC Framework – Figure 4]:
    - Hazard identification. This involves identification of primary climatic variables (e.g., temperature, precipitation, storm tracks), and variables directly affected by climate changes (e.g., sea level, streamflow runoff) that may represent hazards.
    - Understanding exposure and vulnerability to enable risk identification. This step involves identifying the pathways that link hazards to risk (i.e., cause-and-effect pathways), including decision-making criteria identified at Stage 2. Risk end-points are taken forward into the risk evaluation.
    - Risk evaluation. This involves analyzing the likelihood of occurrence and severity of consequence.

- **Stage 4 –** Identify options: At this point, adaptation options are identified that are robust to climate change, and provide the greatest likelihood of meeting the objectives and criteria defined in Stage 2. In particular, focus is placed on finding 'no regret' and 'low regret' options. [In the IPCC Framework (Figure 4), an intermediate step is included before "Identify Options" – "Evaluate trade-offs"].

- **Stage 5 –** Appraise options: Options appraisal is closely linked with risk assessment and comprises evaluation of the adaptation options against the success criteria established in Stage 2. The purpose of the options appraisal stage is to provide a robust basis upon which to identify and recommend the preferred option to meet the overall decision criteria. [Although this is not explicitly mentioned in the IPCC Framework (Figure 4), this is likely to be covered by iteration in the "Analysis" cycle].

- **Stage 6 –** Make decision: This is the final stage before implementation and involves bringing the information together, evaluating it against the objectives and defined decision criteria.

This may include a review of whether the decision objectives and criteria remain appropriate in the light of the preceding analysis. [Although this is not explicitly mentioned in the IPCC Framework (Figure 4), this is an inherent part of moving between "Analysis" and "Implementation" phase in the IPCC Framework – Figure 4].

- **Stages 7 and 8 –** Implement and Monitor: These represent post-decision actions and encompass a large variety of potential activities, which are context-specific. [This is identical to the "Implementation" phase in the IPCC Framework – Figure 3].

Stages 3, 4 and 5 are tiered (represented in Figure 3 by the overlapping boxes). Willows and Connell (2003) identify three tiers: Tier 1 – preliminary risk assessment; Tier 2 – qualitative and generic quantitative risk assessment; Tier 3 – specific quantitative risk assessment. The differences between the three tiers are outlined in Table 1. In practice, the decision-maker will undertake a different level (tier) depending on:

- the level of decision (i.e., policy, program or project);
- the level of understanding they have about how climate change will affect their decision, which will be determined in part by previous assessment iterations; and
- whether they are making a climate adaptation decision (in which case they will have already identified climate change as a significant risk as part of a Tier 1 assessment) or a climate-influenced decision (in which case they will be less certain of the implications of climate change).

Table 1: Key to selecting the appropriate tier of risk assessment (Willows and Connell 2003).

	Tier 1 – preliminary climate change risk assessment	**Tier 2 – qualitative, semi-quantitative and generic risk assessment**	**Tier 3 – specific quantitative risk assessment**
Decision level	Policy, Program, Project	Program, Project	Project
Climate change importance to decision-making	Start at this tier if unsure about how, or if, climate change could affect your decision.	Start at this tier if already confident that climate variables are/are not important to your decision.	Use this tier if data are available to support quantitative assessments including climate and impacts.
Decision type	Start at this tier for decisions that may be influenced by climate change.	May start at this tier for climate adaptation decisions, or following Tier 1.	For climate-influenced and climate adaptation decisions, once a range of adaptations options has been identified in “assess risk-appraise options-identify options” loop.
Purpose of risk assessment	For preliminary risk screening, in particular: • identify factors that might be a present or future climate hazard within the exposure unit (acceptable confidence level: low, medium or high); • exclude factors that are not a present or future climate hazard (acceptable confidence level: high); • exclude potential receptors not a significant risk (acceptable confidence level: high); • help to identify, in broad terms, potential climate risk management options under Stage 4.	For risk characterization, prioritization and ranking, in particular: • identify influence, dependencies, causal pathways linking climate to receptors; • assess the (relative) sensitivity of a receptor to climate (and non-climate) hazards, based on agreed assessment endpoints; • characterize the nature of the risk posed to the receptor; • priority and rank of climate and non-climate risks; • help to identify or refine Stage 4 options, including climate adaptation and climate change risk management; • help to appraise Stage 5 options, including options for climate adaptation and climate change risk management; • form reasoned judgments on confidence level (or uncertainty) associated with risk assessment, and the performance of risk management options; • identify important assumptions	Essential where the choice between option, or the effective management of the risk, will be improved by detailed quantitative assessment of the risk or uncertainties, including exploring the sensitivity of the assessment to key assumptions.

In summary, our climate change risk assessment approach provides an analysis of risks to an installation's function and mission caused by physical changes in climate conditions, along with consideration of non-climate factors, such as interactions with neighboring landholders. It is intended to help decision makers understand the key changes in climate that are of relevance to the installation and identify informational needs across DoD operations to build adaptive capacity. As applied in a single workshop context, our risk screening is a high-level analysis at the installation level. As mentioned below (Section 3.1.4), Tier 2 and 3 risk assessments, using one-to-one consultation activities with operational and/or managerial and financial experts, increase the specificity of the risks identified for individual installations; Tier 3, in particular, employs spatial analysis tools, and sensitivity and exposure analyses, process modeling and other quantitative assessment—in order to address the priority risks related to mission success.

Our framework is consistent with the key principles of user-engaged science (for three reasons:

1. It is an iterative process, which incorporates feedback at a number of stages. The framework is iterative and acknowledges the fact that climate change risk management is an ongoing process that will need to adapt as new evidence, policies, technologies, and other factors emerge.

2. It is flexible, in order to accommodate complexity. Stages 3, 4, and 5 are tiered, which allows the decision maker to identify, screen, prioritize and evaluate climate and non-climate risks and options, before deciding whether more detailed risk assessments and options appraisals are required. This helps prevent unnecessary costs by avoiding the immediate use of time consuming and sometimes costly quantitative assessments. Like adaptive management, this tiered method is a "bottom-up" approach for making robust decisions today in the face of an uncertain future climate. The focus is initially placed on finding those adaptation options that reduce vulnerability to past and present climate variability, as well as non-climatic pressures. If the lifetime of a project, infrastructure, or resource management strategy spans several decades, climate scenarios can be used to test and appraise whether the options continue to provide the desired level of protection (Wilby and Dessai 2010). If they fail, then decisions can be made to immediately adjust options or apply incremental adaptation over a period of time—allowing new information to inform revisions to the adaptation options.

3. It emphasizes the importance of an open, collaborative approach to decision-making. The framework stresses the importance of taking into account the legitimate interests of stakeholder and affected parties. By encouraging active participation, the risk of overlooking potential impacts, and of failing to identify adaptation-constraining decisions will be minimized. This will also ensure that differences in the perception of risks and values are fully explored within the risk assessment and decision appraisal process.

3.1.4 Expert Risk Assessment Approach

Our expert risk assessment approach uses a semi-quantitative technique applied to risks identified by workshop participants. The expert assessment was conducted by the Acclimatise members of our research team, and was informed by their previous work with departments of defense. The expert assessment approach requires application of existing risk management methodologies used by the appropriate military branch. We were only able to procure existing risk management methodologies from the U.S. Navy; consequently, we were only able to apply the approach described below to Naval Base Coronado. A complete description of this method is included in the White Paper on Risk Assessment Methodology, submitted to SERDP in April 2014 (UA SERDP Project RC-2232 Team 2014). A summary of results is presented below in Section 4.1, and a detailed account of results is presented in Appendix C.

Risk assessment and prioritization

The mechanics of the risk assessment process draws on existing U.S. Navy risk management methodologies, in order to ensure that the process is familiar to installation personnel and that the outputs can be easily integrated into existing threats, hazards and consequences procedures. The evaluation of climate risks for NBC utilizes the Navy Installation Emergency Management Program Manual (CNI 3440.17), Standard 4, hereafter referred to as 'The Manual' may be viewed in Appendix C,

The Manual notes that *"Emergency Management planning must be predicated on critical asset, threat/hazard, vulnerability, consequence, and response capability assessments. These assessments are used to evaluate an installation's ability to respond to a threat/hazard, protect the population on the installation and implement future strategies to mitigate risks"* (U.S. Navy 2006).

Risk is defined in The Manual as being: *"a function of threats/hazards, vulnerability to threats/hazards, and resulting consequences if these threats/hazards were to strike a critical infrastructure on an installation"*. The following equation is used to provide a quantitative assessment of the relative risks posed:

$$\text{Risk} = \text{Critical Infrastructure (CI)} \times [\text{Threat (T) or Hazard (H)}] \times \text{Vulnerability (V)} \times \frac{\text{Consequence (C)}}{\text{Response Capability (RC)}}$$

Each of the components of this equation, and assumptions made in our application of the equation to climate change risk assessment are discussed in more detail below. Importantly, we assume that that no additional adaptation measures are in place to address climate change (i.e. the green line in Figure 5) – rather than rating risks post-adaptation (red line in Figure 5). This will allows personnel to consider how significant the risks of climate change could be, if no adaptation action is taken.

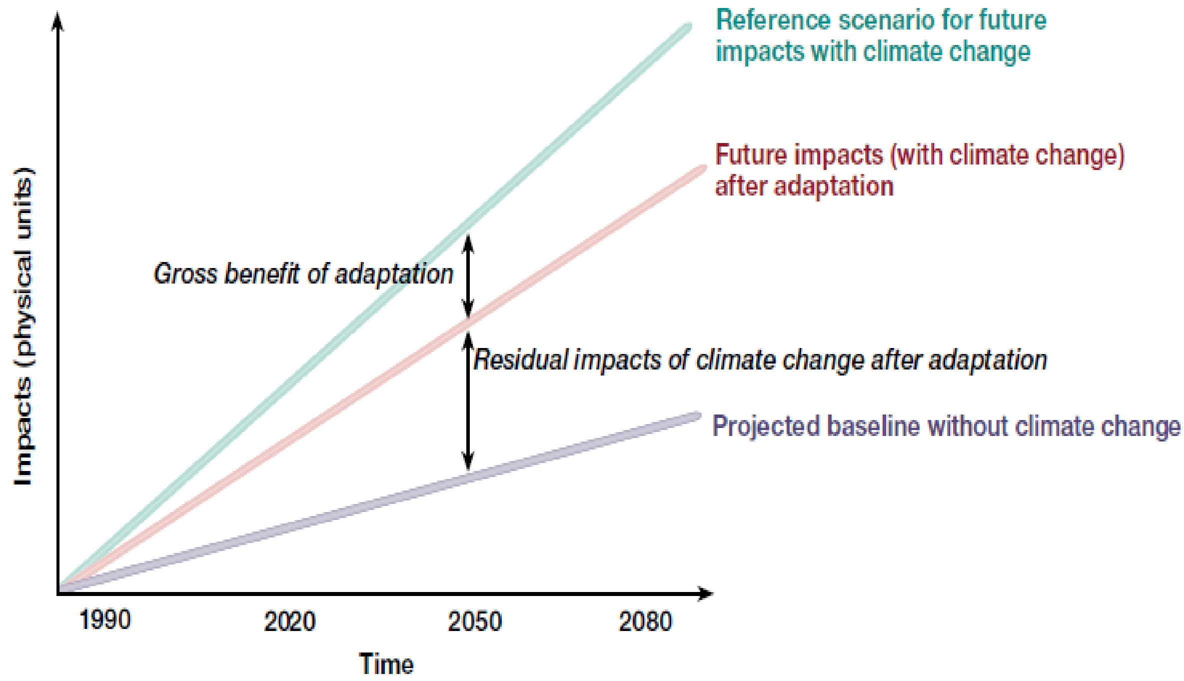


Figure 5. Illustration of climate change risks in absence of adaptation (difference between green line and blue line) and residual risks post-adaptation (difference between red line and blue line) (Metronomica 2004).

Risk causal narrative
To provide consistency of description, risk causal narratives have been developed which clearly outline the "cause", "process" and "consequence". An example is provided in 2.

Table 2. Example risk causal narrative. Risk reference codes relate to the workshop breakout groups, where risk was originally identified: O = Operations, F = facilities, T = Training and EN = Environment.

Risk ref no.	Causal narrative		
	Cause (climate driver)	Process	Consequence
F12	More frequent heavy downpours of rain	causes flooding of underground infrastructure	with the consequence that critical IT, power and water supply may be affected

In cases where climate drivers were unspecified and simply termed *"climate change"* or *"global warming"*, we used the standardized term *"incremental climate change"* to describe the slow, 'creeping' manifestations of longer-term climate change (e.g. increase in temperatures over several decades). This term has also been used in cases where specifying the exact climate drivers is particularly challenging (e.g. factors that determine outbreaks of infectious diseases).

We used the term *"extreme events"* to describe acute climate variability, both over short and longer timescales.

- An *extreme weather event* is typically associated with changing weather patterns, that is, within time frames of less than a day to a few weeks.
- An *extreme climate event* happens on longer time scales. It can be the accumulation of several (extreme or non-extreme) weather events (e.g., the accumulation of below average rainy days over a season leading to substantially below average cumulated rainfall and drought conditions).

Some climate extremes (e.g., droughts, floods) may be the result of an accumulation of moderate weather or climate events (this accumulation being itself extreme). Compound events, that is, two or more events occurring simultaneously, can lead to high impacts, even if the two single events are not extreme per se (only their combination). Finally, not all extreme weather and climate events have extreme impacts.

There is an increasing body of empirical evidence suggesting that extreme weather events have become more common in recent years, and the majority of scientists relate the increased frequency and intensity of such events to climate change. Looking forward, the recent IPCC report (2012) on extreme weather events judged it *"very likely that the length, frequency, and/or intensity of warm spells or heat waves will increase over most land areas"* and *"likely that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21st century over many areas of the globe"*.

The generally well-documented nature of extreme events has generated greater interest in planning for more severe and frequent climatic events. In contrast the 'creeping' average changes are much harder to recognize and are more likely to be overlooked. Consequently, we sought to identify the risks associated with both incremental changes and extreme events and the terminology used in the risk causal narratives highlights this distinction.

Critical infrastructure (CI) value

Using the guidance provided in The Manual, NBC is an operational base and therefore we assigned all risks a critical infrastructure value of 2. Our risk assessment was undertaken at a strategic / installation-wide scale (rather than individual asset-scale), the critical infrastructure value has been standardized across all risks.

Threat (T) or hazard (H) probabilities

As shown in Table 3 the hazard assessment criteria is composed of two elements: Hazard Relative Probability (Values) and Onset Values. Each of the climate drivers were assigned a Hazard Relative Probability score, as shown in Table 3. For the Onset Values, each individual risk causal narrative was reviewed and the definitions outlined in The Manual were applied unchanged.

Table 3. Hazard Relative Probability score for each of the climate drivers assessed

Relative ranking	Climate driver	Hazard Relative Probability	Reasoning
1	Incremental climate change	10	Based on observed climate data over the past few decades, warming of the climate system is unequivocal (IPCC 2013). The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased. There is high confidence and high certainty that these trends will continue over the next few decades, irrespective of efforts to reduce greenhouse gas emissions, due to inertia in the climate system.
2	Sea Level Rise	10	There is high confidence and high certainty.
3	Extreme high temperatures	10	There is high confidence and high certainty.
4	Warmer and drier	2	Warmer is very certain, but drier (less precipitation) is less certain. Some of the uncertainty regarding precipitation is due to natural year-to-year and decade-to-decade variations.
5	Extreme events	1	There is moderate confidence and certainty that the frequency and intensity of extreme events will increase. There is great certainty regarding heat waves, than uncharacteristic precipitation-related events (e.g. droughts, El Niño rains).
6	More frequent heavy downpours	1	Currently, there is no trend in this statistic.
7	Sea level rise and higher wave surge	0.5	Sea level rise is very likely, but future higher wave surge is unknown because future changes in storm intensity are highly uncertain and the science of modelling wave surge from coarse-scale (i.e., modelled storm system) data is not refined enough for looking at the spatial scale of the NBC beachfront.

Vulnerability (V) value

As defined in The Manual, critical asset vulnerability values for natural hazards are assessed based on the following criteria:

- Compliance with building construction codes and HAZMAT Storage/Handing codes;
- Sheltering-in-Place, Evacuation Plans, Mass Notification System; and
- EM Awareness Training.

For our assessment, each individual risk causal narrative was reviewed and the definitions outlined in The Manual were applied unchanged, based on our team's professional judgment, as informed by feedback from installation personnel, to validate our assessment. We assumed that compliance with health and safety, and environmental regulation, will be particularly stringent and as such, risks containing these elements were typically given a low vulnerability value.

Consequence (C) value
The consequence value is based on a sum of the following criteria (each of which has a 5-point scoring scale):

- Installation Death or Injury;
- Installation/Asset Infrastructure (includes environmental remediation by EPA); and
- Asset Mission Capability.

For our assessment, we reviewed each individual risk causal narrative and we applied the definitions outlined in The Manual unchanged, based on our team's professional judgment.

Response capability (RC) value
Using the guidance provided in The Manual, NBC's existing response capabilities are Group 1; therefore all risks were assigned a response capability value of 8 (the factor under consideration is a Natural Hazard).

3.1.5 Tier 2 and Tier 3 Methods for working on a specific climate change risk, and for further risk-specific discussions of climate adaptation strategies

At two installations, NBC and FTH, following our initial climate risk screening, we followed up with more detailed assessment, employing extensive consultation, modeling, spatial analysis and other methods. The Tier 2 and 3 interactions relied on a less structured approach of one-on-one dialogue with natural resources staff, in order to address the particular risks related to wildfire on DoD installations. This level of interaction allowed us to more clearly and viscerally connect immediate concerns and actions with the implications of potential future climate changes; this approach has also opened the door to further discussion of climate change in relation to other installation-level decisions. The interactions are described within the spatial analysis and modeling methods.

3.2 Methods for assessing current sea level rise risk, and projecting future risk at Naval Base Coronado

The combination of sea level rise, storm surge, and coastal flooding is a potent climate change-related risk along the California coast (Caldwell et al. 2013). Soon after initiating project RC-2232, we learned of a detailed investigation and assessment of these factors at Naval Base Coronado (NBC), and the potential of their impacts to NBC built infrastructure through the processes of erosion, tides, flooding, and inundation (Chadwick et al. 2015; SERDP RC-1703). This obviated the need for our team to conduct further sea level rise research. We proceeded to cooperate with Chadwick and colleagues, and we focused on interpretation of their 554 page

report, as a climate service to NBC staff.

Key research question – What sea level-focused climate services are needed to make the detailed assessment of Chadwick et al. (2015) most useful to those not specializing in climate and sea level at NBC? Can the information contained in the RC-1703 study be used in concert with seasonal climate information to improve preparation for short-term events, such as the 2014-2015 El Niño event?

Methods – We used a focus group webinar to inquire about NBC staff needs and uses for RC-1703 information. The focus group informed us of the potential need for information products that related the RC-1703 (long-term focused) study to shorter-term climate risks, such as an upcoming El Niño episode. We followed up with multiple "translational information products" integrating results from the RC-1703 report with the climate-related risks identified in the work by the University of Arizona and Acclimatise.

Evaluation – We followed up with numerous requests for evaluation of these experimental information products, which generated no response. We conducted a project update phone interview, in February 2016, to ascertain NBC actions related to sea level rise and El Niño episodes. *Opportunities for further research* – There remain opportunities for further research in determining different uses and applications of the datasets generated in Chadwick et al. (2014), including retrospective analysis of impacts at NBC during the 2014-2015 and 2015-2016 El Niño events in comparison to the modeled results in the dataset.

Suggested reading

Chadwick B, et al. (2015). A methodology for assessing the impact of sea level rise on representative military installations in the southwestern United States. (RC-1703). Technical Report 2037.April 2015. San Diego: SSC Pacific, 554p.

3.3 Methods to assess vegetation response to climate extremes and fire at Naval Base Coronado inland training facilities.

Risk to inland training facilities from extreme wildfire events was identified as a primary concern at the initial risk assessment engagement at Naval Base Coronado. Climate projections in this region suggest increased frequency and duration of extreme drought conditions. These conditions combined with a high frequency of human-caused ignitions are likely to continue the trend of more frequent and larger wildfires in many southern California ecosystems. Concerns were centered around loss of operational training capacity as well as the ability of the base to meet its obligations to protect threatened and endangered species present on DoD-administered lands.

Several of the inland training facilities are embedded within the Southern California chaparral ecosystem, a vegetation type that is adapted to high-intensity fire but that has been shown to be sensitive to the persistent drought conditions projected under changing climate (Coates et al. 2015). While several large, high severity fires have burned over much of the surrounding chaparral landscape over the past two decades, more than 90% of the vegetated area

administered by DoD has not experienced fire in more than 70 years. Extreme fire behavior of chaparral systems pose significant threats to infrastructure and personnel; and the intensity of fire effects is a function of available dry fuels that accumulate over prolonged fire free periods. This system is also home to the Quino Checkerspot butterfly, an endangered species with unknown tolerance for fire or other disturbances to its host chaparral species community.

Key research questions - Are the chaparral ecosystems under the stewardship of DoD at risk relative to climate-change type drought and fire conditions? Are there proactive steps that could be taken to mitigate near-term and long-term risks associated with changing climate in this system and how do near and longer-term risk mitigation strategies differ?

Methods - We used a series of national vegetation maps calibrated by a network of independently verified georeferenced locations to determine the relationship between chaparral types located on DoD lands and those present over the greater southern California chaparral ecosystem. Using an atlas of historical fire occurrence, we developed a map of relative vegetation age and then combined this age map with the vegetation type distributions to identify vegetation most similar to the types and ages represented on DoD lands (Figure 6).

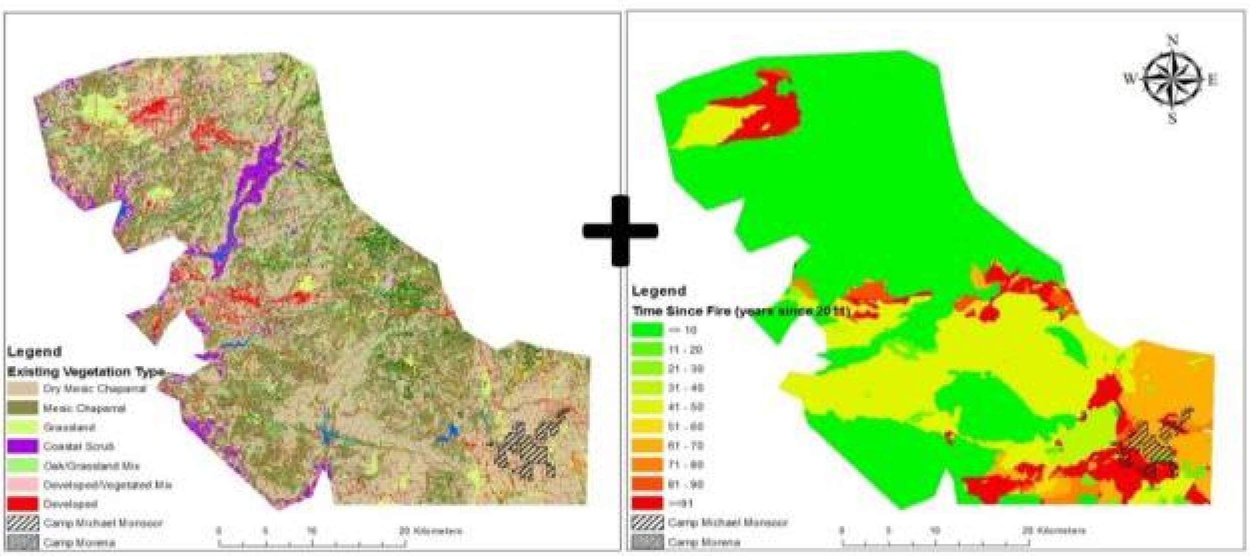


Figure 6. Mapping of chaparral vegetation by age class to assess climate vulnerability.

We used LANDSAT image stacks to develop a time series of vegetation response to drought using the Normalized Difference Moisture Index (NDMI) (Dennison et al. 2005) calculated over the April-October curing season from 1984-2011. Finally we selected a series of fires of varying size and severities that occurred in chaparral types similar to those on DoD facilities and tracked pre and post-fire vegetation response to climate as well as post-fire vegetation recovery as a function of seasonal moisture and temperature trends.

Evaluation- This series of methods can be used to characterize vegetation response to climate and fire over large landscapes. The space-for-time method of assessing landscape vulnerability that draws upon the global spatial extent of LANDSAT imagery allows for inclusion of a broad range of temperature, moisture and disturbance conditions over the relatively short operating life

of the environmental monitoring program. By focusing analysis on time periods where fire-climate interactions are most representative of those projected for the region, this method provides a comparison-based projection of how a landscape of interest is likely to respond given changing climate, occurrence of fire, or both.

Opportunities for further research - The complex interactions between chaparral age, climate sensitivity, and fire provide ample opportunities to further test potential outcomes for this system. Importantly, management actions designed to increase climate resilience of chaparral systems may well exacerbate post-fire recovery. Efforts at pre-fire planning to coordinate response and develop shared fire management strategies are having the intended effect of limiting fire intensity? in other southwestern landscapes. However, in southern California the patchwork of federal, state, and private ownerships surrounding DoD lands coordinate their fire response with the California Department of Forestry and Fire Protection (CalFire) without an overarching fire planning or management objective system. As the likelihood of fire continues to increase on these landscapes, significant opportunities exist for the DoD to take the lead in coordinating pre-fire planning to reduce hazards to sensitive natural resources and built assets, increase fire management efficiency, and develop a cohesive series of management objectives that allow for risk-informed fire planning and management across ownerships and time scales.

Suggested reading

Coates, A. R., P. E. Dennison, D. A. Roberts, and K. L. Roth. 2015. Monitoring the Impacts of Severe Drought on Southern California Chaparral Species using Hyperspectral and Thermal Infrared Imagery. Remote Sensing 7:14276-14291.

Dennison, P. E., D. Roberts, S. Peterson, and J. Rechel. 2005. Use of normalized difference water index for monitoring live fuel moisture. International Journal of Remote Sensing 26:1035-1042.

Scott, J. H., M. P. Thompson, and D. E. Calkin. 2013. A wildfire risk assessment framework for land and resource management. General Technical Report RMRS-GTR-315, USDA Forest Service Rocky Mountain Research Station.

Weng, Q. ed., 2011. *Advances in Environmental Remote Sensing: Sensors, Algorithms, and Applications*. CRC Press.

3.4 Methods for modeling projected climate and fire interactions in forested landscapes at Fort Huachuca

DoD installations embedded within larger natural landscapes are exposed to a range of environmental hazards that often originate outside DoD ownership. In addition, the diversity of ecosystems under management by DoD are subject to the same federal protections as all other federally managed lands and reasonable actions must be taken to prevent the loss of ecosystem function and the destruction of federally listed sensitive species. In the fire-prone mountainous landscapes of the Southwestern U.S., the diversity of plant and animal species constrained to a small geographic area heighten the need to understand climate-associated risks to potentially sensitive ecosystems and the potential for disturbances such as fire to accelerate climate-driven shifts (Falk 2013). At Fort Huachuca, more than half of the installation is embedded within a formerly fire-adapted landscape that underwent a century of fire exclusion followed by a series of recent large, high-severity fires that may be changing the vegetation-trajectory of the burned over ecosystems. The largest and most destructive of these fires was stopped at the edge of the Fort after burning through a residential area and thousands of acres of National Forest and park lands. The abundance of fuels remaining on the DoD side of the fire scar and climate projections that forecast a lengthening fire season and more frequent and severe drought conditions have raised concerns about the likely effects of changing climate on future fire and changes to the ecological function of the Huachuca Mountains.

Key research question - How is climate change likely to affect the forests of the Huachuca Mountains and how might it influence the size and frequency of future fires?

Methods - We selected the ecosystem process model FireBGCv2 (Keane et al. 2011) to simulate projected climate effects on primary forest species and fire effects at the landscape scale. FireBGCv2 is a tree to landscape scale, spatially explicit model designed for use in montane environments with steep ecological gradients and diverse terrain (Figure 7). The model tracks individual vegetation response variables that determine the growth, reproduction, and mortality of hundreds of thousands of individual trees. A separate probabilistic fire simulator allows fire to propagate across a landscape depending upon historic ignition patterns, available fuels, and daily weather conditions. Model outputs can be summarized at annual time steps. FireBGCv2 requires daily weather streams for each simulated environmental condition. We used the Mountain Climate Simulator (MT-CLIM) (Hungerford et al. 1989) to project daily weather from nearby weather stations onto a user-specified number of biophysical settings determined by elevation, aspect, and solar angle. For climate change scenarios, daily weather stream products developed from regionally downscaled GCM projects are appropriate inputs. We selected a subset of GCM outputs, deemed appropriate for the region and atmospheric processes of interest, from the statistically downscaled Multivariate Adaptive Climate Analogues CMIP5 GCM catalogue (MACA 2014) covering a range of dates that overlap with recent climate (for calibration) and extending several decades into the future, reflecting DoD planning horizons.

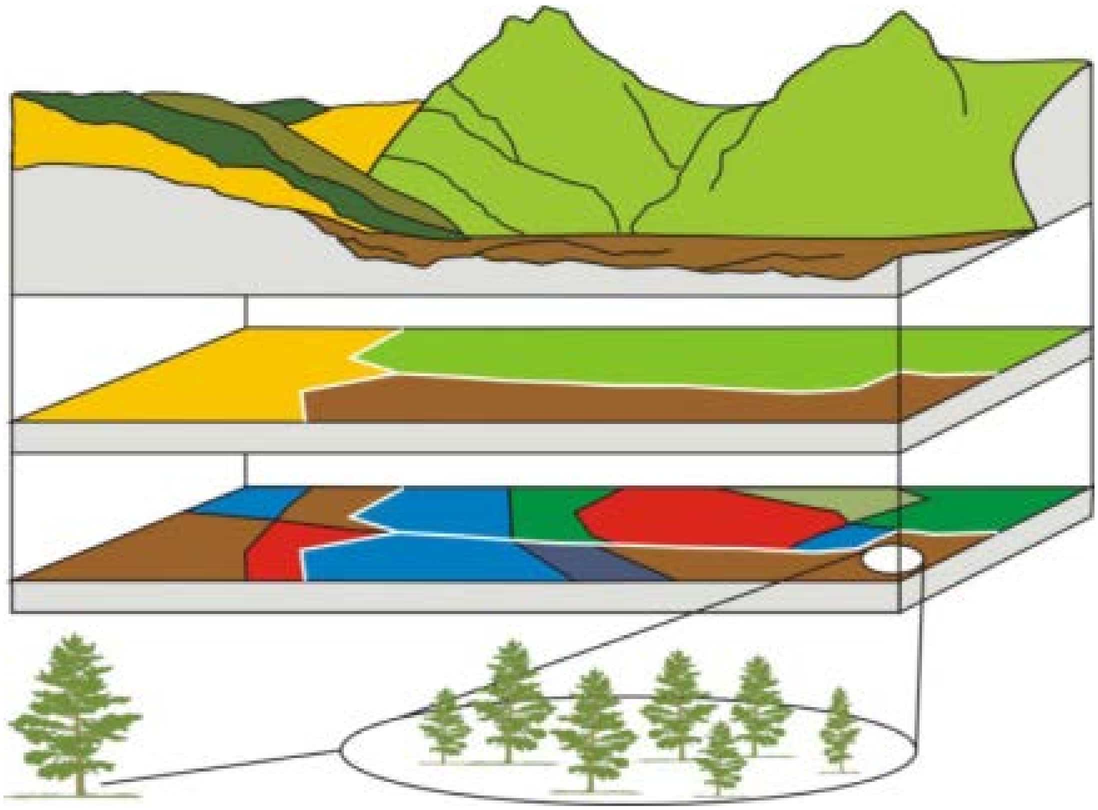


Figure 7. Structure of nested tree, plot, stand, and site layers that make up the FireBGCv2 simulation landscape.

Evaluation - Outputs produced by the FireBGCv2 model track more than 100 variables summarizing changes to landscapes at scales from individual trees to stands, forests, and landscapes. Different levels of fire suppression or fuel modification treatments allow the user to separate out the effects of climate, fire, and management actions for their effects on vegetation distributions, ages, structural characteristics, and fire outcomes. Some example model outputs include spatial representation of discrete time steps reflecting species distributions, fire burn severities, and forest basal area in each simulation year. Landscape-summarized outputs track changes to total ecosystem carbon and proportion of the landscape burning at low, moderate, or high fire severity over time. In Figure 8 the model is projected onto the landscape of interest:

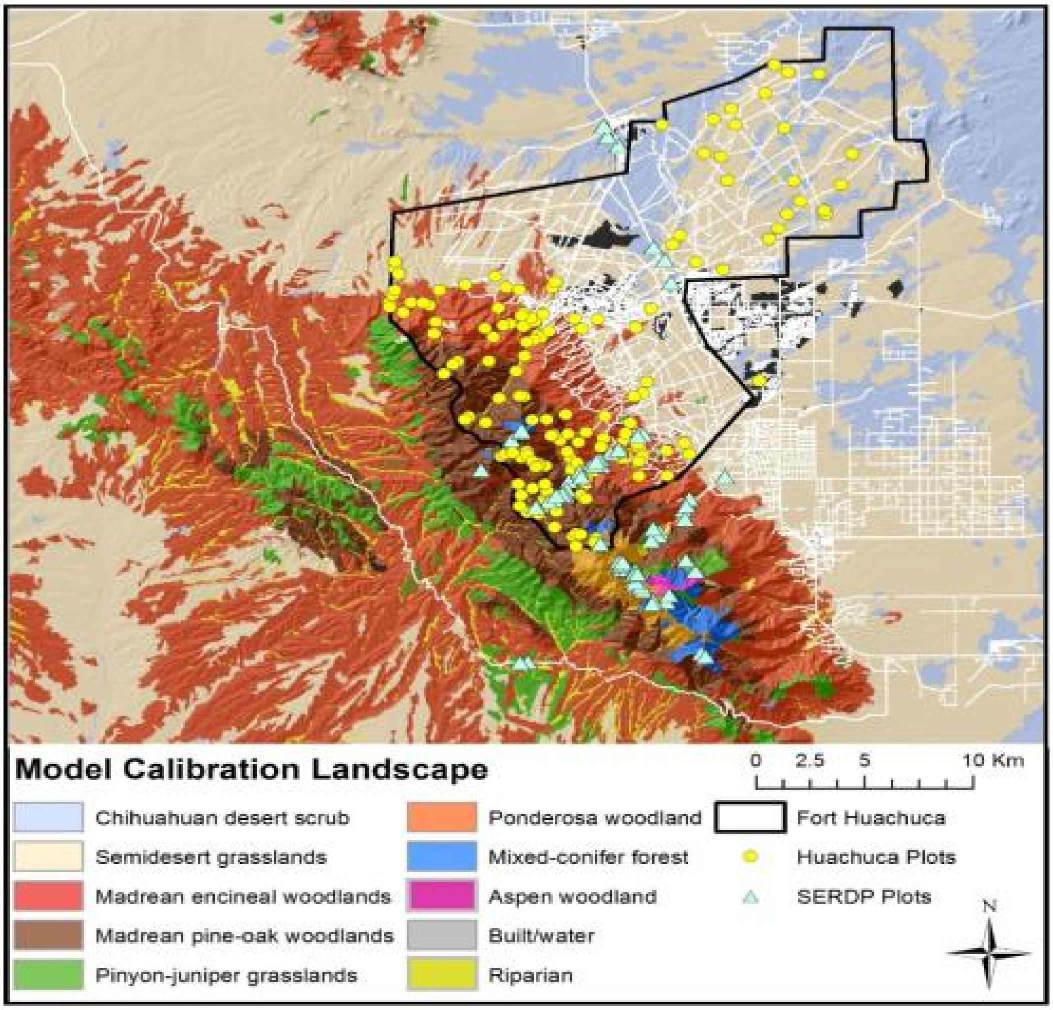


Figure 8.The distribution of ecological response units and sampling plots used for model calibration.

Each of the 10 distinct vegetation zones received a different daily weather stream based on elevation and solar exposure. Individual tree counts and size distributions from sampled plots were used to develop the simulation landscape.

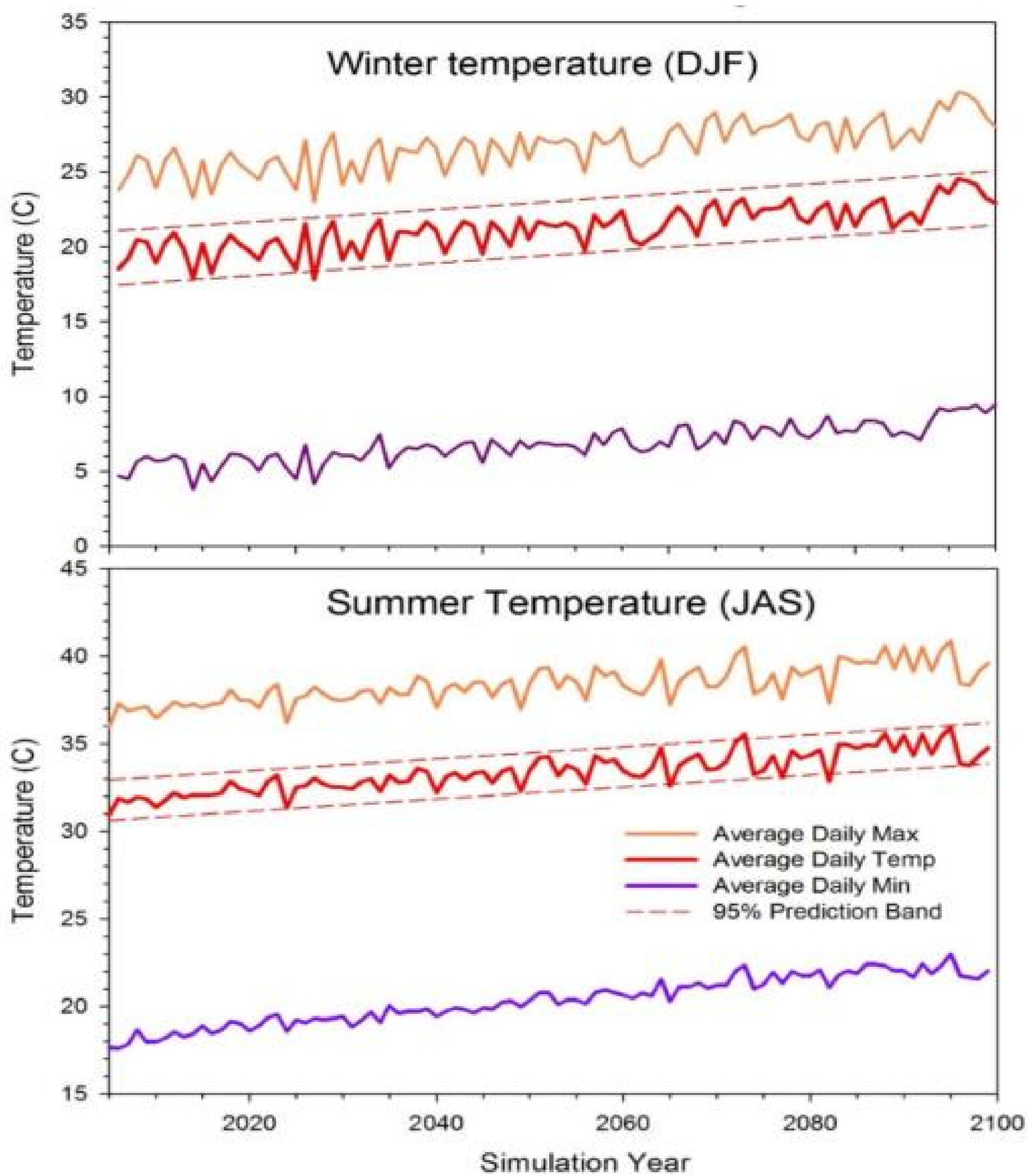


Figure 9. Projected temperature for Sierra Vista, AZ from 2005-2100 used for landscape model simulations

Figure 9 above is an example of projected temperature for Sierra Vista, AZ from 2005-2100 used for landscape model simulations. Winter temperature is the daily average for December, January, and February. Summer temperature is the daily average for July, August, and September. Projections are generated from the Multivariate Adaptive Climate Analogues (MACA) statistical regional downscaling of CMIP5 Can ESM2 Global Climate Model using the RCP 8.5 scenario (MACA 2014). Individual model projection is used for illustrative purposes only and is one of only three GCMs identified by Sheffield et al. (2013) capable of modeling the dynamics of the North American monsoon system with less than 30% error when compared against 30 years of historical data.

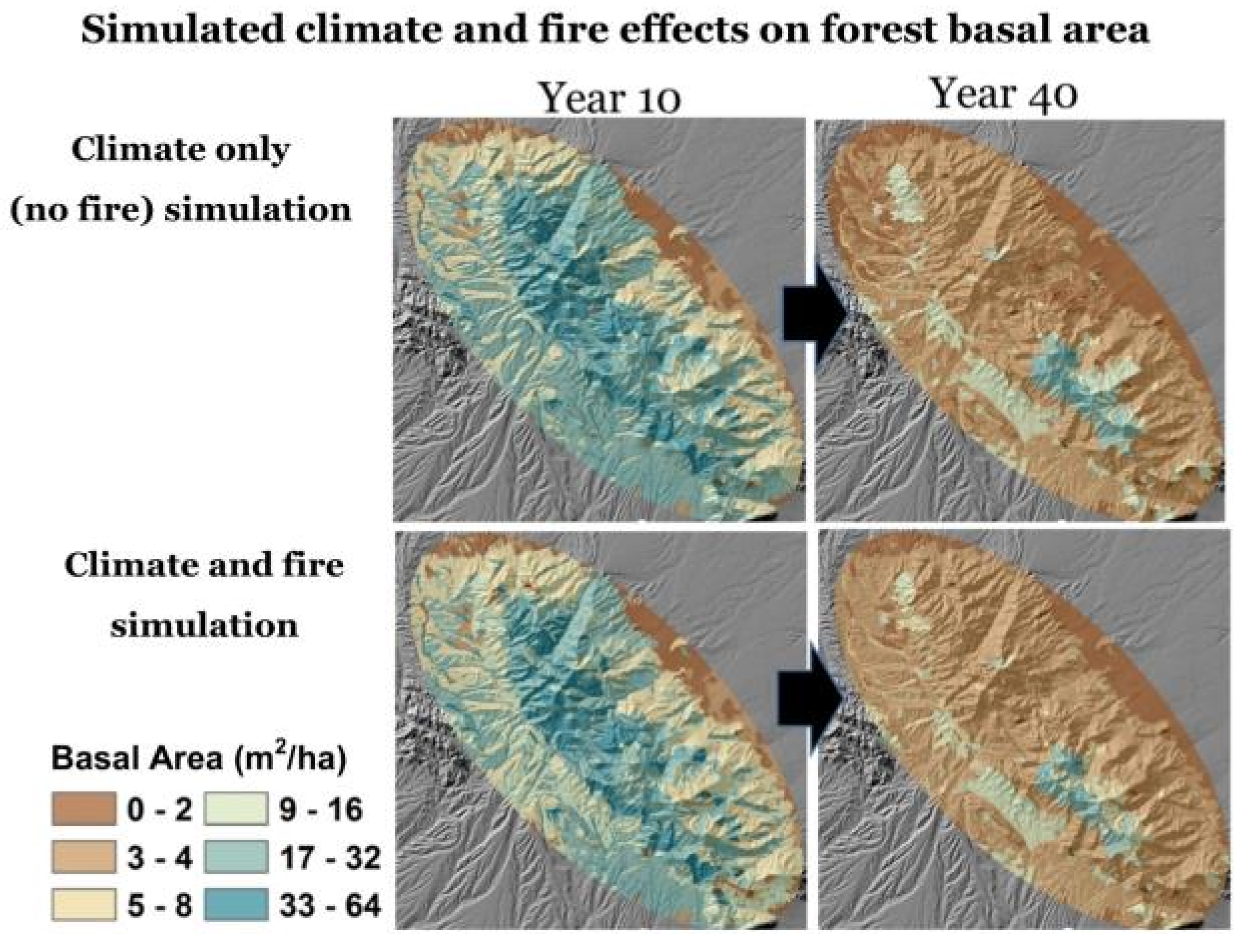


Figure 10. Example spatial output of landscape change under future climate with and without fire.

Opportunities for further research - FireBGCv2 allows the use of a range of potential management interventions to modify landscape fuels, change fire suppression tactics, update the accuracy of the starting landscape conditions, and utilize improved climate model projections such as those being developed by Dr. Christopher Castro on a concurrent SERDP project. While time investment and data needed to initiate the model are significant, once an initial landscape is developed, updating model inputs is a straightforward process. Few tools exist to objectively evaluate the potential efficacy of climate change adaptation actions. For DoD installations embedded in western forested systems, projections from a simulation system such as FireBGCv2 can be used to assess potential climate threats to a range of DoD natural resources and built assets (Figure 10). Incorporation of climate scenario modeling has potential to support adaptation decision making and resource allocation at local and regional scales.

Suggested reading

Falk, D.A., 2013. Are Madrean ecosystems approaching tipping points? Anticipating interactions of landscape disturbance and climate change. In: Gottfried, G.J., Ffolliott, P.F., Gebow, B.S., Eskew, L.G., Collins, L.C., Merging Science and Management in a Rapidly Changing World: Biodiversity and Management of the Madrean Archipelago III. RMRS P-67. May 1–5, 2012. Tucson, AZ U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Fort Collins, CO. pp. 40–47.

Hungerford, R. D., R. R. Nemani, S. W. Running, and J. C. Coughlan. 1989. MTCLIM: a mountain microclimate simulation model. USDA Forest Service Intermountain Research Station, INT-414. Ogden, UT. 55 p.

Keane, R. E., R. A. Loehman, and L. M. Holsinger. 2011. The FireBGCv2 landscape fire and succession model: a research simulation platform for exploring fire and vegetation dynamics. USDA Forest Service Rocky Mountain Research Station, Ft. Collins, CO.

Rollins, M. G. 2009. LANDFIRE: a nationally consistent vegetation, wildland fire, and fuel assessment. International Journal of Wildland Fire 18:235-249.

3.5 Methods for modeling future flood risk as a function of changing climate and fire activity.

Flooding and debris flows following wildfire threaten public safety and are a major cause of economic and environmental damage. Changing climate conditions are likely to exacerbate an already heightened threat, as fuel conditions that promote high fire severity coincide with lengthening fire seasons, warming temperatures, and increasing biotic stress to forests and shrublands. Post-fire flooding is of heightened concern in mountainous areas of the Southwest U.S. that experience high-intensity monsoon rains immediately following the late-spring fire season. Over the past two decades, flooding following large, high-severity fires has caused significant damage to infrastructure and threats to humans and wildlife in communities in Arizona, New Mexico, Colorado, and California (e.g. Youberg and Pearthree 2011, Grimm et al. 2013).

Key research question - How are changes to forested systems and fire likely to influence peak storm runoff and long-term surface flow trends affecting DoD installations?

Method description - Building on the climate and fire- driven changes to forested landscapes simulated with the FireBGCv2 modeling system, we used annual changes in surface vegetation characteristics and fire burn severity to inform a hydrology modeling framework. With guidance from the installation hydrologist we selected an individual watershed of importance containing a significant concentration of highly valued assets. We compared vegetation structure before and after simulated fire years with hydrology curve numbers to develop watershed-scale inputs for the Automated Geospatial Watershed Assessment tool (AGWA) (Guertin et al. 2008). AGWA is a spatially explicit hydrology modeling framework that facilitates data integration with a range of more detailed hydrology modeling systems. We used the Soil Water Assessment Tool model

(SWAT) (Gassman et al. 2007) to track seasonal hydrologic trends and the Kinematic Runoff and Erosion Model (K2) (Smith et al. 1995) to characterize acute storm runoff (Figure 11).

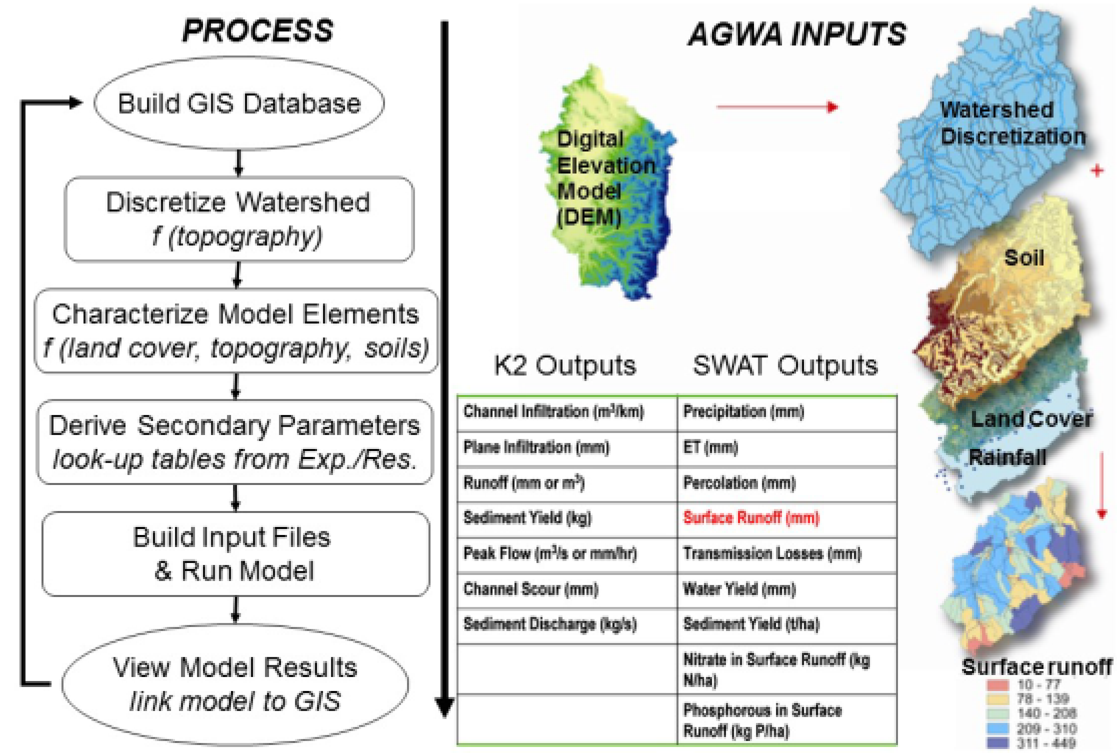


Figure 11. Conceptual design of Automated Geospatial Watershed Assessment tool (AGWA) and integrated hydrological modeling components. K2 is the Kinematic Runoff and Erosion Model and SWAT is the Soil Water Assessment Tool model. Adapted from D. Goodrich, U.S.

Evaluation - AGWA allows the results from physical hydrology models to be projected onto specific landscapes and the use of individual storm events familiar to base personnel. As an example, we used an individual high-flow run-off event in 2014 that occurred in an unburned watershed and resulted in significant damage to road infrastructure as the type of event that might become more common if monsoon storm activity intensifies. We modeled this storm event over the watershed of interest and assessed changes to run-off over simulated climate time with fire activity. This allowed for a direct comparison of projected changes to runoff against a recent storm with known outcomes. This kind of direct comparison of potential future risks against recent base experience can be a powerful tool for attracting the interest of base personnel in further engagement with the scientific community and is useful in communicating longer-term climate risk.

The spatial representation of fire and flooding outcomes clearly connects climate effects on one system to its effects on secondary systems, and in this case possibly with more pressing risks. Connecting simulation models facilitated understanding of the link between current and future fire risk and its effects on flood potential and damage to critical infrastructure (Figure 12).

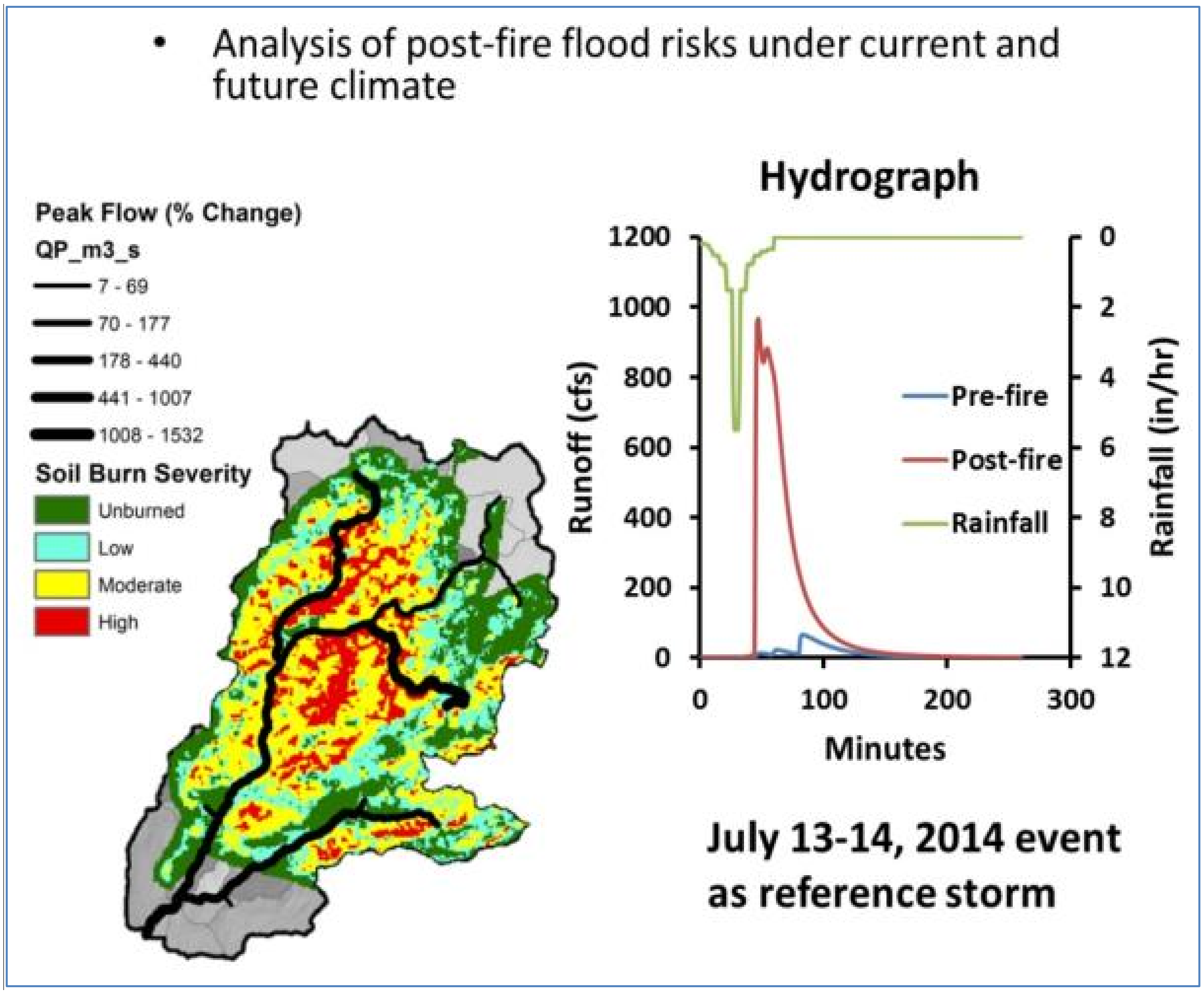


Figure 12. Spatial projection of stream flow outputs changing as a function of fire severity and response to monsoon storm event. This methodology can be used on simulated fire and run-off events under projected climate and landscape conditions.

Opportunities for further research - Unlike the initial fire and vegetation change modeling, the example hydrology modeling work did not include an analysis of the effects of potential management actions. The framework used here addresses potential risks but not potential adaptation. Additional modeling incorporating fuel treatments within the forested landscape or other management interventions could serve to identify means of limiting current and future flood risks. This type of hydrologic modeling, tied to climate change and ecosystem process changes, has broad application where DoD installations are exposed to post-fire flood risks. Additionally, long-term modeling of surface flow trends could be used to project potential water constraints or water conflict issues with other surface water users. The incorporation of changes

to vegetation and fire from projected future climate provides a more complete assessment of climate risks associated with water scarcity or over-abundance.

Suggested reading

Gassman, P.W., M. R. Reyes, C. H. Green, J. G. Arnold. (2007). The Soil and Water Assessment Tool: Historical Development, Applications, and Future Research Directions. *Transactions of the ASABE*. Vol. 50(4): 1211-1250.

Grimm, N. B., M. D. Staudinger, A. Staudt, S. L. Carter, F. S. Chapin III, P. Kareiva, M. Ruckelshaus, and B. A. Stein. (2013). Climate-change impacts on ecological systems: introduction to a US assessment. Frontiers in Ecology and the Environment 11:456-464.

Guertin, D.P., D.C. Goodrich, W.G. Kepner, D.J. Semmens, M. Hernandez, I.S. Burns, A. Cate, L.R. Levick, and S.N. Miller. 2008 (see pp. 49-50). Automated Geospatial Watershed Assessment (AGWA)—A GIS-Based Hydrologic Modeling Tool for Watershed Assessment and Analysis. In Norman, Laura M., Hirsch, Derrick D., and Ward, A. Wesley, eds., Proceedings of a USGS Workshop on facing tomorrow's challenges along the U.S.-Mexico border; monitoring, modeling, and forecasting change within the Arizona-Sonora transboundary watersheds: U.S. Geological Survey Circular 1322, 63 p. [http://pubs.usgs.gov/circ/1322/c1322.pdf].

Smith, R.E., D.C. Goodrich, and J.N. Quinton, (1995). Dynamic, distributed simulation of watershed erosion: The KINEROS2 and EUROSEM models, Journal of Soil and Water Conservation, 50(5):517-520.

Youberg, A. and P. Pearthree. (2011). Post-Monument Fire floods and debris flows in the Huachuca Mountains, southern Arizona. January 5, 2015, http://azgeology.azgs.az.gov/article/environmental-geology/2011/09/post-monument-fire-floods-and-debris-flows-huachuca-mountains.

3.6 Methods of examining connections between current threats to operations and future climate change risk

Base staff and commanding officers must respond to immediate and near-term risks. Without placing future risk into the context of current concerns, in our experience, climate change messages may not be perceived by DOD personnel as worthy of their limited time, attention, and resources. Through articulating the level of magnitude of the threat - in relation to past or imminent threats – our team provided installation staff with a scale through which they can judge the prospects for successfully addressing these risks. By integrating climate change risks into the current decision matrix and linking projected threats to current or past threats, our team studied how active engagement with personnel at the installation level builds capacity by framing future challenges in the context of more familiar here-and-now concerns.

Key research question - Does integrating longer-term climate change risks into the decision matrix used to address recent or current threats to operations and personnel facilitate active engagement and planning for these longer-term risks?

Methods - To examine connections between current threats and future risks at the installation level, we followed up on the findings from initial risk assessment workshops by engaging directly with resource managers. In discussions with managers we formulated a series of research questions addressing perceived links between current or recently experienced climate-related threats to installation operations, personnel, or training. We used these discussions to prioritize climate challenges and to explore a range of available information and methods to address one or more of the highest priority climate challenges at each installation. We used a combination of existing datasets provided to us by the installations, new field-collections to augment existing data, and regional and national geospatial information ground-truthed by local personnel or researchers from our project.

Evaluation - Methods used to integrate and analyze data ranged from simple summarizing of currently available information, to more detailed statistical analysis of landscape change trends to determine climate associations, to labor intensive custom modeling of projected climate effects to ecosystem processes and hydrology. We then used preliminary results from our analyses to discuss climate-associated risks with resource management personnel and to modify our approach when necessary to better align research outputs with installation relevant climate concerns. Final products were then presented to a larger audience of operations personnel, resource managers, and commanding officers at each installation to discuss how locally applicable climate risk information can be integrated into current planning, funding, and operational frameworks (see Appendix D and Appendix E).

Suggested Reading

O'Connor, C.D., Treanor, F., Falk D.A., Garfin, G.M., (2016). Climate change-type drought, temperature, and fire effects on Naval Base Coronado inland training sites, San Diego County, California. Strategic Environmental Research and Develop Program (SERDP) Project RC-2232 Interim Report 3. University of Arizona School of Natural Resources and the Environment, University of Arizona, Tucson. 29 p.

O'Connor, C.D., Sheppard, B.S., Garfin, G.M., Falk D.A. (2015). Quantifying post-fire flooding risk associated with changing climate at Fort Huachuca, Arizona. Strategic Environmental Research and Develop Program (SERDP) Project RC-2232 Interim Report 2. University of Arizona School of Natural Resources and the Environment, University of Arizona, Tucson. 31 p.

O'Connor, C.D., Garfin, G.M., Falk D.A. (2015). Projected climate change impacts on vegetation, fire, and wildlife habitat at Fort Huachuca, Arizona. Strategic Environmental Research and Develop Program (SERDP) Project RC-2232 Interim Report 1. University of Arizona School of Natural Resources and the Environment, University of Arizona, Tucson. 34 p.

3.7 Methods used to illuminate adaptive strategies in use by other sectors

The Acclimatise, U.K. team focused on identifying broad lessons learned across international defense programs. The aim of this research was to a) review climate adaptation practices from the defense departments of other nations that have already implemented climate resilience building measures, and b) highlight examples from other federal agencies and private sector industries to provide a foundation for climate change-related decision-making for the U.S. DoD.

This mode of the research targeted four areas of decision-making, namely:

- Assessment of climate vulnerabilities and impacts (including tiered levels of assessment);
- Adaptation options appraisal;
- Mainstreaming climate change considerations into organizational structures; and
- Role of external stakeholders in decision-making processes.

Key research questions-

1. Given numerous climate vulnerability and impact assessment methods, what are the best and most promising practices for the U.S. DoD to draw upon?
2. What are the decision-making processes and tools that can be employed to overcome the challenges of climate uncertainty?
3. What are the informational (e.g. climate data), technical, financial and institutional needs across different methods? What will be the challenges for the DoD in meeting these needs?
4. How are stakeholders (e.g. relevant Federal agencies) to be included in decision-making – what are pitfalls and opportunities?
5. How do these needs differ across hierarchies of “decision-makers” and operational areas, such as workplace health and safety, environmental management, infrastructure planning and maintenance programs?

Methods - Acclimatise reviewed peer reviewed and grey literature as well as supplemental case studies from analogous decision making processes. Their strategy focused on foreign defense forces, and public and private sector decision making strategies in the context of adaptation to current and future climate change projections in the light of uncertainty. The Acclimatise, U.K. team simultaneously conducted a series of semi-structured military of Australian and UK defense personnel and sector practitioner interviews to inform their understanding of barriers and opportunities to mainstreaming climate change adaptation.

Evaluation – The Acclimatise literature review included international defense organizations, with emphasis focusing on evidence from the UK and Australia where noted organizational-level advances have been made in recent years. To complement cases studied, Acclimatise called upon more readily available information from the public and private sectors, and in particular those organizations that share similar characteristics to DoD, namely, organizations with a reliance on

large, long-lived assets with large workforces and the need to manage natural resources carefully to maintain operational continuity. Due to increased Ministry of Defence (MoD) and private and public sector interest in assets and capacity building, a wide range of assessments and action plans were identified through the following case studies to be discussed in both sections 4 and 5:

Defense Entities Examined:

- Australian Ministry of Defence
- United Kingdom Ministry of Defence

Non-Defense Entities Examined:

- The State of California
- The Ports of San Francisco, Los Angeles and Humboldt Bay, California
- The City of New York
- Port Authority of New York and
- Port Authority of New Jersey
- Extractives (Mining and Energy Sectors)

Suggested Reading

Ministry of Defence (2010). MoD Climate Change Delivery Plan. Available from: http://webarchive.nationalarchives.gov.uk/20121026065214/http://www.mod.uk/NR/rdonlyres/AFAFEF28-1CFB-44F2-BCCC-15ABB00766D9/0/MoDClimateChangeDeliveryPlan2010FINAL.pdf

United Kingdom Ministry of Defence (2012). Building a Climate Resilient Estate - A Practitioner Guide. Defence Infrastructure Organisation. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/33599/20120529PG01_12BuildingaClimateResilientEstateFinalv10U.pdf

3.8 Methods of co-identifying institutional barriers and opportunities

DoD personnel are already fully engaged in a range of tasks related to fulfilling the agency's existing missions. Thus, developing strategies to address future concerns can be challenging because they appear to distract from current and immediate mission focus. Framing climate change risk in the context of current threats to operations and mission support may help provide incentives to mainstream climate change adaptation into decision making processes and institutional structures. Similarly, understanding the roles of leadership and institutional culture is also key to supporting climate change adaptation. Through a collaborative cross-project workshop involving natural resource managers, researchers from other SERDP projects and DoD personnel, and a series of in depth interviews, the RC2232 project team was able to catalog a core set of institutional barriers to mainstreaming climate change adaptation within DoD decision making, and illustrate opportunities for adapting to climate change in the DoD setting.

Key research questions:

1. To what degree and does the DoD differ from other communities that are working to manage risk?
2. Which aspects of the DoD command and organizational structure serve as barriers or opportunities for integrating climate change adaptation strategies?
3. What institutional incentives are necessary to increase the likelihood of DoD success at embedding climate change considerations in standard operating procedures?
4. How might knowledge derived across multiple SERDP projects inform the implementation of the January 2016 Departmental Directive on Climate Change?
5. How might the research investments of other federal agencies in the area of risk communication and risk management be leveraged or augmented to advance DoD's strategic interests?
6. What are the specific research needs that, if met, would substantially enhance the capacity of DOD to manage risks to its mission and facilities?

Methods - To complement the best practice efforts of the Acclimatise researchers in the United Kingdom, the UA team hosted a cross-project and multi-practitioner workshop in March 2016. Then, to further explore barriers and opportunities gleaned from the March 2016 workshop, the UA team developed a survey instrument and conducted a series of semi-structured ethnographic interviews in the second and third quarter of 2016. The workshop, coupled with subsequent interviews, identified the relevant insights of the DoD personnel and researchers who have had a significant role in climate adaptation research and adaptation efforts. Our workshop and interview findings are embedded throughout multiple sections of this report. The list of questions asked during the UA semi-structured interviews has been provided in the appendix (Appendix A and Appendix B).

Evaluation - Our multipronged approach identified significant barriers and opportunities for mainstreaming climate adaptation, as well as characterized aspects of leadership that may hinder or support climate change research and resilience efforts. More importantly we were able to contribute to the existing body of knowledge in support of a) developing climate services for moving research to application and b) harnessing the lessons learned through the conceptual lens of coproduction of science and policy.

In March 2016 the UA SERDP team hosted a workshop to discuss the transferable lessons that can be learned across DoD climate adaptation projects and to identify research needs in support of climate adaptation. The primary objective was to co-produce and articulate realistic pathways for moving climate research towards applications. Participants included researchers from four SERDP teams, multiple branches of DoD, and contractors familiar with DoD adaptation efforts. We discussed the findings of individual adaptation projects funded by SERDP, identified obstacles to adaptation and opportunities for climate services mechanisms, reviewed and commented on draft hypotheses developed by the University of Arizona (UA) SERDP team, and discussed scalability of SERDP science to meet DoD needs. We used interactive learning approaches, such as facilitated discussion and brainstorming, to share knowledge and experience

across the SERDP projects and geographies. The implications of the DoD Directive 4715.21 Climate Change Adaptation and Resilience, which was issued by the DoD Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics in January 2016, were discussed. The Directive 4715.21, which established policies and responsibilities for managing risks associated with the impact of climate change, was issued two months before the cross-project workshop. It provided an important foundation for the discussion.

Institutional barriers and opportunities for integration of climate science in risk management decisions were identified during the workshop as well as through the ethnographic interview process through a process of joint learning known as "co-production." Co-production is a term widely used to describe the process of engagement between scientists and stakeholders that involves collaborative learning by involvement of multiple parties. Though much has been written about ways to enhance the utility of science for policy and decision-making, the underlying premise of much of the literature is that co-production enhances utility of the information by enhancing the perception that it is trusted, accessible, and useful for decision-making. Though our previous experience with this topic did not include DoD applications, it was our hypothesis that these factors would be relevant in supporting use of climate science and adaptation techniques at military installations. Our approach included evaluation of additional considerations in encouraging the use of scientific information for managing risk in the military context, including understanding the role of leadership and military hierarchy, the role of active duty vs. civilian personnel, "mission-focused" vs. "operations" perspectives in enabling use of scientific information and understanding risk, the capacity to build trusted relationships between our research team and base personnel, and most importantly, demonstrating the relevance and scientific credibility of the information that we produced.

Our strategy here resulted in:

- Triangulating our experiences in engaging with personnel on each of the four military installations with the experiences of other SERDP project research projects
- Facilitating an output driven workshop that resulted in a formal report delivered to SERDP in May 2016
- Development of a cross-project produced survey instrument used in the semi-structured interviews of DoD personnel within various DoD branches and command levels.
- Corroboration of findings through multiple lines of evidence

Opportunities for Future Research - Specific opportunities for future research are comprehensively discussed in section 4 and fall into the following categories:

- Human dimensions research/stakeholder engagement
- Adaptation science support
- Education and training
- Iterative climate services

There is a well-established literature on the topic of co-production of science and policy methods, particularly in the context of producing information that is used and useful in the context of decision-making. The following articles are particularly helpful as background for exploring the issue of bridging the gap between scientific knowledge and application of that knowledge in a decision context:

Dilling, L., and M.C. Lemos, (2011). Creating usable science: opportunities and constraints for climate knowledge use and their implications for science policy. Global Environmental Change. 21: 680-689. doi:10.1016/j.gloenvcha.2010.11.006

Eden, S.(2011). Lessons on the generation of usable science from an assessment of decision support practices. Environmental Science & Policy. 14: 11-19. doi:10.1016/j.envsci.201 0.09.011

Jacobs, K., G. Garfin, and M. Lenart, (2005). More than just talk: connecting science and decision-making. Environment: Science and Policy for Sustainable Development, 47(9): 6-21. doi:10.3200/ENVT.47.9.6-21

Kirchhoff, C.J., M.C. Lemos, and S. Dessai, (2013). Actionable knowledge for environmental decision making: Broadening the usability of climate science. Annual Review of Environment and Natural Resources, 38(3): 1-22. doi: 10.1146/annurev-environ-022112-112828

Lemos, M.C. and B.J. Morehouse, (2005). The co-production of science and policy in integrated climate assessments. Global Environmental Change, 15: 57–68. doi:10.1016/j.gloenvcha.2004.09.004

McNie, E.C. (2013). Delivering climate services: Organizational strategies and approaches for producing useful climate-science information. Weather, Climate, and Society, 5(1): 14–26. doi:10.1175/WCAS-D-11-00034.1

Moser, S. (2009). Making a difference on the ground: the challenge of demonstrating the effectiveness of decision support. Climatic Change, 95: 11–21. doi:10.1007/s10584-008-9539-1

4. Results and Discussion

Introduction

In Section 4 we describe the results of the seven components of our investigations, completed as part of this project. The first three sub-sections (4.1-4.3) describe case study pilot projects conducted with Naval Base Coronado (NBC), jointly with Barry M. Goldwater Range-East and Barry M. Goldwater Range-West (BMGR), and Fort Huachuca (FTH). The case studies allowed us to test risk assessment methods, to evaluate factors needed for successful interactions between climate science teams and installation personnel, and to identify climate services to support climate adaptation planning and implementation.

The next subsection (4.4) addresses lessons learned associated with framing climate risk in the context of current threats to operations and mission support. In essence this section tests our hypothesis, based on the aforementioned case studies, that *integrating climate change risks into the current decision matrix by linking projected threats to current or past threats creates more active engagement by focusing on here-and-now challenges.* Addressing specific issues now builds capacity and willingness to address climate change adaptation into future planning and risk management processes over time and builds interest in science-based solutions. An operational change in response to a specific climate risk will promote consideration of climate change risk into associated planning and will help to stimulate incorporation of climate change risk throughout the planning process. We use the example of fire and post-fire flood risk assessment and strategy development, to illustrate the insights gained through this participatory research process.

The next subsection (4.5) evaluates the roles played by leadership, institutions, and military culture, in fostering climate change thinking, risk assessment, and adaptation planning and implementation. The analysis, based on interviews with various DoD personnel answered the following research questions:

- *What institutions and incentives are necessary to increase the likelihood of DoD success at embedding climate change considerations in standard operating procedures?*
- *What are the DoD-relevant insights that other sectors can provide?*

Subsection 4.6 evaluates best practices for climate-related decision-making, in the face of multiple uncertainties. The analysis, based on a combination of (a) interviews with climate adaptation planners and experts from international departments of defense, heavy industries, and urban planners, and (b) literature review of best practices from entities with infrastructure assets and decision-making complexity analogous to the DoD, answered the following research questions:

- *Given numerous climate vulnerability and impact assessment methods, what are the best and most promising practices for the U.S. DoD to draw upon?*
- *What are the decision-making processes and tools that can be employed to overcome the challenges of climate uncertainty?*
- *What are the informational (e.g. climate data), technical, financial and institutional*

needs across different methods? What will be the challenges for the DoD in meeting these needs?

- *How are stakeholders (e.g. relevant Federal agencies) to be included in decision-making – what are pitfalls and opportunities?*
- *How do these needs differ across hierarchies of "decision-maker" and operational areas, such as workplace health and safety, environmental management, infrastructure planning, maintenance programs?*

The final study (Subsection 4.7), garnered lessons for moving climate change research to applications (R2A), through the insights gained from a workshop attended by investigators from multiple SERDP climate change projects, personnel from various levels in the DoD hierarchy, and private sector contractors that have worked on DoD or SERDP projects. The study addressed the following research questions:

- *Is DoD different from other communities that are working to manage risk? If so, in what ways? (e.g., culture, leadership, turnover issues?) What are the implications?*
- *What does the scientific community know right now that can be useful to DOD facilities in managing risk? What products can the scientific community deliver on a timely basis? How can DoD personnel efficiently evaluate the confidence, accuracy, and precision of projected climate conditions and risks?*
- *How should individual facilities access relevant information for decision support from external sources such as other federal agencies, universities, and NGOs, and efficiently identify the state of knowledge relative to climate risks?*
- *How can installation personnel best assess the "ripeness" of information for decision support?*

The results presented are from studies designed to explore methods useful to communicating climate-related risks, scientific findings and information, to convey the importance of adaptation planning for changing climate and weather conditions, and to identify intervening factors that may serve as barriers to or opportunities for success. The results are not intended as comprehensive evaluations of methods for climate risk assessment, decision support services for climate change adaptation planning and implementation, or processes for successful communication and introduction of climate change content and thinking into routine DoD practice. However, collectively, each study examines a facet of the overall challenge of establishing adaptation to climate change as a standard practice at U.S. DoD installations. In particular, the results are not intended to demonstrate the implementation of climate adaptation practices at installations, as the project was not authorized or funded to conduct ongoing climate adaptation services, but rather to glean insights that can be applied at multiple installations and across the DoD. These studies were influenced by profound changes in our project, that were instigated by the untimely death of the original lead-PI, Dr. Rafe Sagarin. The direction of the project was amended by the team, with the consent and approval of Dr. John Hall, as reflected in a white paper submitted to SERDP in August, 2016 and revised in October, 2016. Consequently, not all topics are covered in equal depth, as we shifted our focus over time from case studies in providing services at individual installations, to studies aimed at identifying practices, barriers, and opportunities related to more systemic climate adaptation services.

To inform participants in the aforementioned studies about the prospects of future climate changes, we used the following combination of climate model projections, and sea level rise estimates:

- At Naval Base Coronado, our first case study (May 2013), we presented climate projections of temperature and precipitation for three time periods, 2021-2050, 2051-2070, and 2071-2099, as compared with a baseline of 1971-2000. We used the SRES Panel on Climate Change Special Report on Emissions Scenarios (SRES) A2 (high emissions) and B1 (low emissions) greenhouse gas emissions scenarios, in order to be consistent with authoritative sources, such as the Southwest technical input report (Garfin et al. 2013) to the National Climate Assessment (Melillo et al. 2014). We used an average of projections from global climate models (GCMs) from the Climate Model Intercomparison Project 3 (CMIP3). We presented additional regional climate model projections from the North American Regional Climate Change Assessment Program (NARCCAP), which were developed for the National Climate Assessment; these projections were forced with SRES A2 emissions, for the time period 2041-2070.

- At the Barry M. Goldwater Ranges (February 2015) and Fort Huachuca (May 2015), we presented projections from the Climate Model Intercomparison Project 5 (CMIP5), forced with the RCP 8.5 emission scenario (Moss et al., 2010) which is similar to the SRES A2 (high emissions) scenario in the middle of the century. Again we used an average of GCM projections from CMIP5.

- To estimate the influence of sea level rise on local water levels at Naval Base Coronado, we applied projections described in Caldwell et al. (2013), which were based on the 2010 California Climate Action Team (CCAT) interim guidance. CCAT guidance used 2000 as a baseline year. We supplemented this information with storm and wave surge analyses (Chadwick personal communication of analyses ultimately published in Chadwick et al. 2015), based on the combination of a 1 m rise in sea level, combined with a 100-year storm.

Research at NBC began in Spring 2013 and continued through the end of 2016. Research at BMGR began in Spring 2014 and continued through the Spring 2016. Research at FTH began in Winter 2013 and continued through the Fall 2016. The sequential nature of the case studies allowed for many of the lessons learned at one installation to be incorporated and tested at subsequent installations. Evaluation of the roles of leadership, institutions, and military culture began in Spring 2016 and continued through Fall 2016. The best practices evaluation work began in Winter 2015-16 and continued through Fall 2016. The cross-SERDP project workshop and assessment began in Spring 2016 and continued through Summer 2016. These latter projects, initiated after the change in lead-PI, informed each other at many stages—by design—which allowed interview methods and evaluation insights to be shared across projects.

4.1. Case study results: Naval Base Coronado

Naval Base Coronado (NBC) was the first installation in which we tested our risk assessment methodology. We selected NBC for its exposure to a variety of climate-related effects, as a U.S. Navy installation, and based on NBC's strong interest to collaborate with our team. NBC presented an interesting combination of climate exposures and sensitivities, because the base consists of multiple coastal and inland units, and it coexists with the large metropolitan area in and around San Diego, California. Its relative proximity to the University of Arizona facilitated site visits and interactions between investigators and installation personnel.

The study included the following activities:

1. Convene initial off-site meeting
2. Develop stakeholder engagement plan
3. Collect initial data, including documentary research, and telephone interviews with liaisons and other key personnel
4. Convene risk and vulnerability assessment workshop, at NBC
5. Prepare formal risk assessment
6. Present written risk assessment report
7. Debrief and present risk assessment results through webinars and teleconferences; determine the focus of specialized collaborative follow-up investigations and climate impact information products
8. Conduct collaborative follow up research on climate-related fire risks at inland training facilities Camp Michael Monsoor and Camp Morena; (N.B.: we report on the climate-related fire risk follow-up research in greater detail in Section 4.4)
9. Develop and test climate information products and sea level rise report translation
10. Conduct follow up interview with liaison
11. Present written climate and fire effects report (see Appendix F)
12. Debrief NBC, Camp Michael Monsoor, and Camp Morena personnel on climate and fire effects report

Using the risk assessment methodology described in Section 3.2.3 as a guideline for a structured risk dialogue process, we convened a workshop with personnel from NBC and representatives of several relevant external stakeholder entities adjacent to NBC land holdings. The main objectives of the workshop were to (a) identify and discuss key climate risks to NBC, (b) discuss how existing risks are managed and how these may change in the future, (c) identify the information gaps for adequately managing future risks, and (d) begin to identify information, models and tools needed by NBC to manage priority climate risks. Functional work groups focused on operations, facilities, training, and environment. The agenda, below (Appendix C – first reference the Acclimatise NBC RISK REPORT – and within that report, it is Appendix 2), gives an overview of our structured process, encompassing the following steps:

- Project and workshop overview
- Recent weather-related events, impacts, responses –*exploration of installation exposure to weather and climate*
- Installation objectives and success criteria –*exploration of functional groups and risk receptors, to help establish cause-and-effect connections between climate and*

achievement of the installation's mission

- Future climate scenarios – *exploration of potential future risks and opportunities, changing sensitivities, thresholds related to performance and mission success*
- Risk interconnection – *exploration of risks with consequences across multiple functional groups*
- Prioritizing future risk – *evaluation of the highest priority climate-related risks to the installation*
- Risk management, and future risk – *evaluation of roles, responsibilities, current procedures, needs, barriers, and opportunities associated with future management of the highest priority risks*

We followed up the workshop with a formal, semi-quantitative, risk assessment (Appendix C - Acclimatise NBC risk report). From post-assessment discussions with NBC personnel, we determined the most useful climate change adaptation follow-up activities: more detailed risk assessments related to wildfires at inland training facilities, and development of climate service products related to sea level and coastal storm surge. These second-level (Tier 2) climate change risk assessment and adaptation decision support experiments provided us with deeper insights for: understanding the type and value of information needed to assess future climate change risks, identifying tools to generate information at spatial and temporal scales useful to end-users, and assessing approaches to developing resilient climate change risk assessment and decision-support strategies. In Section 4.1.9 we discuss the merits of the approaches used in this case study and present case study conclusions that contribute to our overall understanding of climate change risk assessment and adaptation planning for DoD installations in the southwestern U.S.

4.1.1. Background

NBC is the largest command in the southwest region of the United States. It is comprised of the main site Naval Air Station North Island (NASNI) and seven special areas, shown in Figure13 and outlined in Table 4. The eight installations employ more than 27,000 military and civilian personnel and encompass more than 57,000 acres, combining airfields, ports, training ranges and facilities to provide critical operational training and services for the entire Navy under one command. For this risk assessment, the distinction has been made between "coastal" and "mountain" installations; the assessment does not go to the level of detail of individual installations.

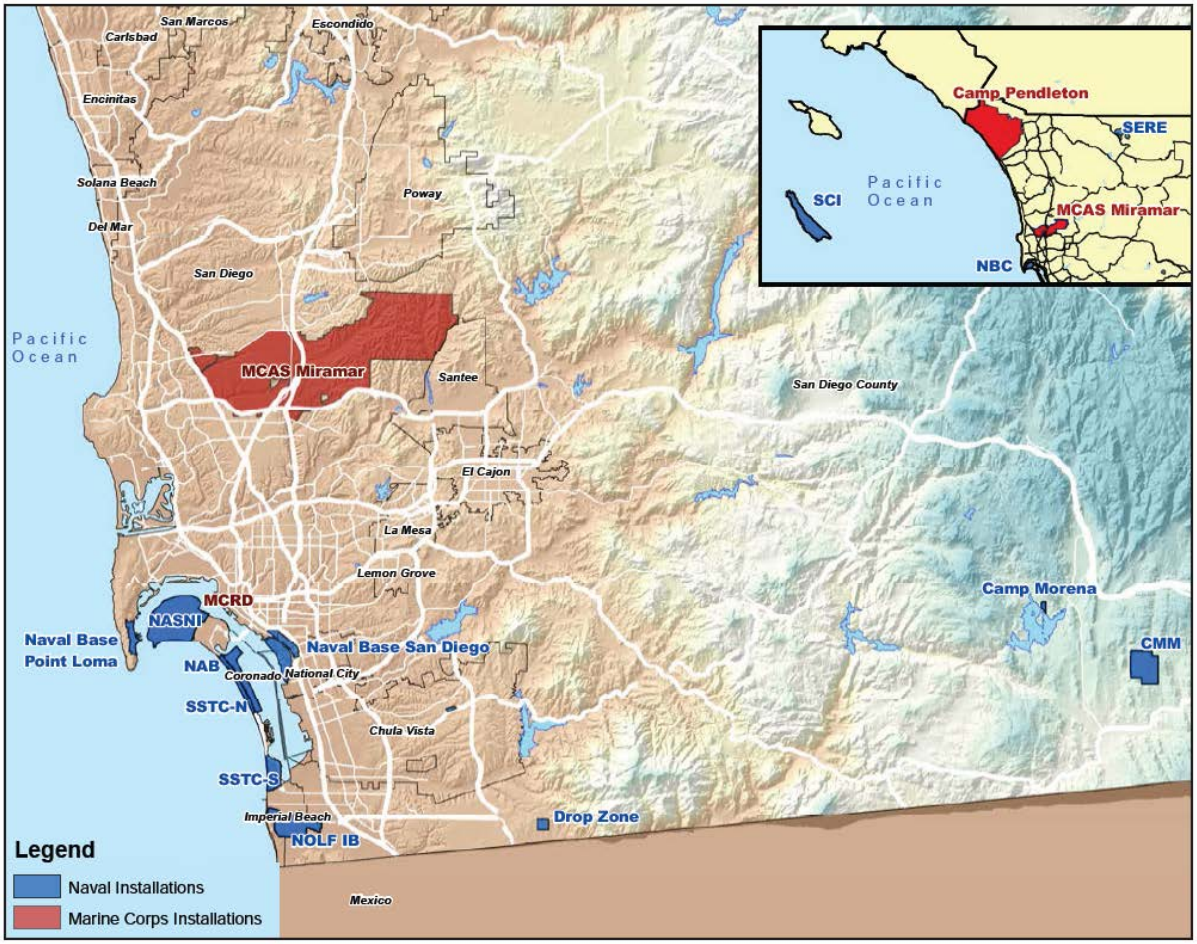


Figure 13. NBC and surrounding military installations (Source: Naval Facilities Engineering Command (2010). Naval Base Coronado Activity Overview Plan.)

Table 4: Installations forming part of NBC (Naval Base Coronado website – http://www.cnic.navy.mil/regions/cnrsw/installations/navbase_coronado/about/installations.html)

Installation	Location	Size	Functions / notes
Naval Air Station North Island (NASNI)	Southwest of Downtown San Diego and adjacent to the City of Coronado	2,397 acres of land area and 406 acres of water	• Host to 23 squadrons and 80 additional tenant commands and activities • Only Navy airfield on the West Coast that is collocated with the piers serving its fleet carriers • Direct air access for aircraft needing to reach ships offshore
NBC Naval Amphibious Base (NAB)	Southeast of NASNI, on the Silver Strand and in the middle of the municipal limits of the City of Coronado	1,091 acres on both water and land	• West Coast hub for naval amphibious operations, including training and special warfare. • State Route 75 (SR-75) bisects NAB
Silver Strand Training Complex (SSTC)	Imperial Beach / Coronado border	450 acres	• Premier training facility for the military's special forces • Waterborne approaches from both the Pacific Ocean and San Diego Bay sides. The

Installation	Location	Size	Functions / notes
			city-like layout of the base also provides a realistic site for critical urban warfare training • Land leased from the State of CA
NBC Naval Outlaying Landing Field (NOLF), Imperial Beach (IB)	10 miles south of NAB on the U.S.-Mexico border, within the City of Imperial Beach and is 14 miles south of Downtown San Diego	1,257 acres	Functional components and their associated areas: • Airfield and airfield easements (1,256 acres), • Mowed grasslands around the airfield (242 acres), • Roads and developed areas (276 acres), • Leased agriculture/grazing (128 acres), • Leased land to Department of Labor Job Corps Center, (25 acres), and • Remaining portion of the base is managed by the U.S. Fish and Wildlife Service (USFWS) as a part of the Tijuana River National Estuarine Research Reserve/Tijuana Slough National Wildlife Refuge
NBC Naval Auxiliary Landing Field (NALF), San Clemente Island (SCI)	Pacific Ocean approximately 68 nautical miles west of San Diego	37,000 acres	• Provide readiness training for units and personnel who deploy overseas • Ranges off the SCI shores – the primary range covers over 149,000 square miles and is the Navy's busiest fleet airspace
Camp Michael Monsoor (CMM), La Posta	50 miles east of San Diego, south of Interstate 8 (I-8) and north of State Route 94 (SR-94)	1,079 acres	• Complex includes an administration building, 5 firing ranges, a close quarters combat training complex, classrooms, and barracks • Located on Bureau of Land Management (BLM) land • Bordered on the north by the Cleveland National Forest and BLM lands on the south, east, and west
Camp Morena, La Posta	North of Lake Morena County Park, near Campo, San Diego County	-	• Mountain and cold weather training
Survival, Evasion, Resistance and Escape Training School (SERE) Facility, Warner Springs	Northeastern San Diego County, at an elevation of about 3200 feet. Located in Cleveland National Forest	-	• Camp consists of a headquarters area with an administrative building, several staff barracks buildings, a wastewater treatment plant and a training compound

NBC's mission is to arm, repair, provision, service and support the U.S. Pacific Fleet and other operating forces (Naval Facilities Engineering Command 2010). In order to support the Fleet, Fighter and Family, NBC's mission is *"to provide the highest quality base operating support and quality of life services to U.S. Navy operating forces and other assigned and visiting activities. We seek to provide the right support, at the right time, in the right amount, enabling*

operating forces to produce the right level of combat readiness” (Naval Base Coronado 2017).

4.1.2. Objectives and success criteria

To understand the broad objectives and success criteria for the installation, each functional group identified their decision-making and success criteria (Table 5). The success criteria provided a tangible link to cause-and-effect chains of events related to observed, and potential future exposure to climate and weather. Participants focused on the following questions:

- *What is our group’s primary role at NBC?*
- *What are the success criteria – or decision-making criteria? i.e. How do we judge success?*
- *What key issues, policies or decisions are we considering now?*

Table 5. NBC success criteria, identified by May 2013 workshop participants.

Operations	Training	Facilities	Environment
Operational Readiness	-	Operable runways, roads & harbor for training and missions	-
		Durability and cost-efficiency of new construction	
Training Readiness	-	-	-
Force Protection	Safety	-	-
Mission Essential Services	-	Uninterrupted power and water supply	-
		Continued operation of IT and communications infrastructure	
Emergency Preparedness	Communication with other Groups on and off Base	-	-
	Mitigating encroachment	-	-
	Working with imposed Legislation/Regulations	-	Compliance

We grouped and reduced the success criteria, which provides the structure for our analysis of climate-related risks and opportunities:

- Mission Essential Infrastructure, Assets and Services;
- Force Protection and Safety;
- Environment and Regulatory Requirements;
- Local communities and Public Relations;
- Training and Operational Readiness; and
- Emergency Preparedness.

4.1.3. Exposure to current and future climate changes

We used a structured approach to introducing climate information, and discussing the exposure of NBC to future climate changes (1) beginning with an initial discussion of recent weather- and climate-related events, episodes, impacts and responses, and (2) following up with presentation of projected regional future climate and specific scenarios tailored to NBC's regional climate and location.

Exercise 1 was used as a pragmatic and effective starting point to understand NBC's recent vulnerability and exposure to severe weather events and the associated direct and indirect consequences. Workshop participants highlighted the following examples:

- Winter storm December 2010, leading to:
  - flooding of Tijuana River
  - damage to pier and waterfront facilities
  - loss of training days, in-water training stopped due to health concerns associated with river flooding
  - loss of access to water for the recreational community
  - transportation problems due to closed roads
  - economic loss to the base due to flooding of agricultural fields
  - clean up and repair exercise with associated economic impacts

- Wildland fires in October of 2003 and 2007:
  - Navy staff death
  - staff sent home
  - operations stopped
  - destruction of endangered species habitat
  - soil erosion and sedimentation build-up in estuary
  - classed as an emergency and fire prevention gains made
  - NBC provided shelter for local communities
  - Fleet ships transitioned off shore power to relieve electrical grid

Historic climate variations pertaining to NBC.

Based on the draft National Climate Assessment, and the technical input report for the Southwest region (Garfin et al. 2013), many locations in the Southwest have experienced warmer temperatures in recent decades, compared to the 1901-1960 average (Figure 14).Since the 1990s, average temperatures have been over 1.5°F (~0.8°C) higher than the 1901-1960 average for the region around NBC. The inset graph in Figure 14 shows that the period from 2001 to 2011 was warmer than any previous decade in the Southwest.

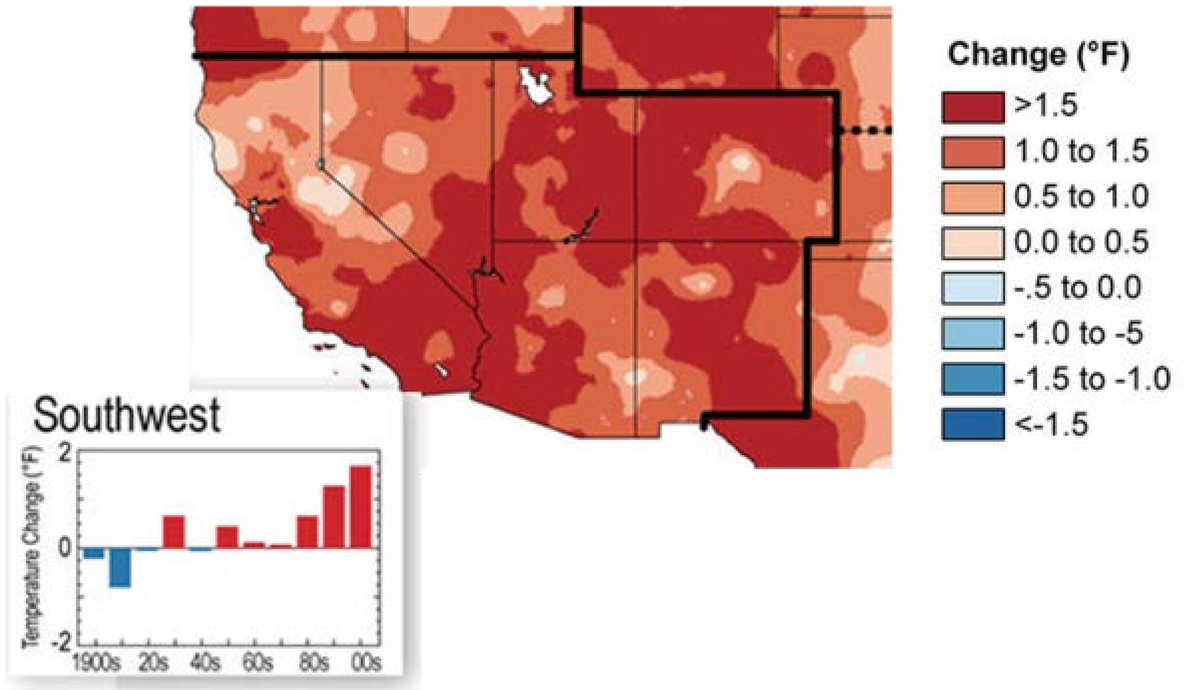


Figure 14. Map shows temperature changes over the past 20 years in °F (1991-2011) compared to the 1901-1960 average. Inset graph show the average temperature changes by decade for 1901-2011 (relative to the 1901-1960 average) for the Southwest region (Data source: NOAA NCDC / CICS-NC; in Melillo et al. 2014).

Concurrent with this warming in average temperatures, there has been a decrease in the number of cold snaps and an increase in the number of heat waves during recent decades (Hoerling et al. 2013). A key point presented to workshop participants is that relatively small shifts in mean climatic conditions, like warmer temperatures, can lead to large changes in the occurrence of extreme events, like heat waves.

There is less of a discernible trend in precipitation across the Southwest region in recent decades, as indicated in Figure 15 in the positive and negative percent changes in annual totals, compared to the 1901-1960 average; the region near NBC shows a slight, but not statistically significant, decrease in annual average precipitation. The inset graph shows the strong decadal precipitation variability in the region, which is characteristic of decadal precipitation variability affecting NBC. For regional precipitation extremes in the context of very heavy daily rain events, there is no clear trend across the region over the past century (Figure 16).

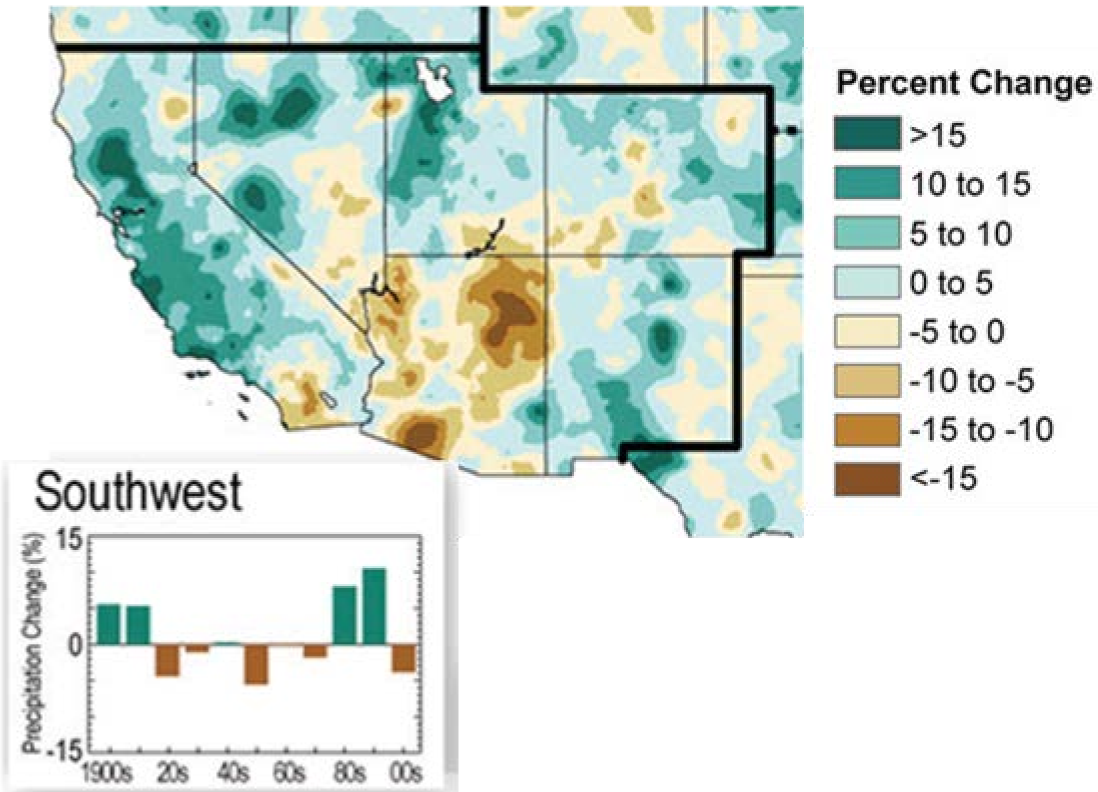


Figure 15. Map shows annual total precipitation changes (percent) for 1991-2011 compared to the 1901-1960 average, and show wetter conditions in most areas. Inset graph shows average precipitation differences by decade for 1901-2011 (relative to the 1901-1960 average) for each region (Data source: NOAA NCDC / CICS-NC; in Melillo et al. 2014).

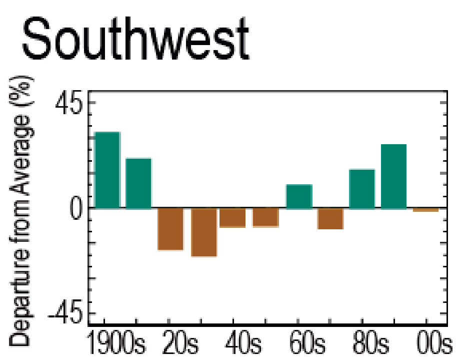


Figure 16. Changes in annual precipitation falling in very heavy events, compared to the 1901-1960 average (Data source: NOAA NCDC / CICS-NC; in Melillo et al. 2014). Heavy events are defined as the heaviest 1% of all daily events from 1901 to 2011.

San Diego depends heavily on surface water supplies, including that of the Colorado River. At the time of the NBC workshop recent annual average Colorado River flows had declined by around 16% thanks to the combination of a 4% decline in annual average precipitation and a 1.3°F increase in Colorado River Basin annual average temperature—when compared with the

1901-2000 mean. These hydrological changes could be reflecting hydrological changes symptomatic of a warmer climate – much like regional observations of earlier snowmelt and losses in snowpack (Hoerling et al. 2013).

Projected future climate for NBC.

In general, the Southwest is expected to continue warming during the 21st century, with longer and hotter heat waves in summer and more intense, severe, and frequent droughts (Garfin et al. 2013). These changes will likely have profound impacts on the natural environment, coastal ecosystems and communities, water resources, energy, agriculture, urban areas, human health and trans-border issues. Our team developed two custom scenarios of future climate for the region encompassing NBC, incorporating the assumptions of the SRES A2 emissions scenario (Walsh et al. 2014). In climate change research, scenarios describe plausible trajectories of different aspects of the future that are constructed to help investigate the potential consequences of man-made climate change (IPCC 2013b). We used these scenarios, described in greater detail in our full risk report (Acclimatise, UK and UA SERDP Project RC-2232 Team (2014)-Appendix C), in order to consider how future climate may affect risks related to successfully meeting NBC's mission.

The two future scenarios for the NBC risk assessment were:

1. Warmer and drier with occasional heavy rainfall; and
2. Higher sea level and higher wave surge.

Scenario 1 – Warmer and drier with occasional heavy rainfall – Climate exposure

Key characteristics of Scenario 1:

- Temperatures rise substantially over the course of the century, with the greatest warming during the summer season (Table 6; Cayan et al. 2013)
- Precipitation declines slightly, but Year-to-year and decade-to-decade variations still result in wet spells and droughts. Heavy precipitation events become more common.
- Warmer temperatures and decreased precipitation reduce snowpack, which lowers streamflow in major river basins (Cayan et al. 2013)

Table 6. Temperature and precipitation projections used in Scenario 1. Values denote annual change in average from 1971-2000 and were drawn from projections based on the high-emissions (A2) scenario in Cayan et al. (2013).

	2021-2050	2051-2070	2071-2099
Temperature	+ 2°F	+ 4°F	+ 7°F
Precipitation	- 2%	- 3%	- 3%

In Figure 17 for example, across all of the future time periods, the greatest increases in average temperatures occur during summer, while in winter the smallest increases occur. The spread in projections is based upon 15 GCM projections for early-, mid-, and late-21st century, relative to the 1971-2000 reference period (Cayan et al. 2013). Such seasonal variation further complicates a scenario where change is greater and/ or harder to predict than simply variations in precipitation and temperature.

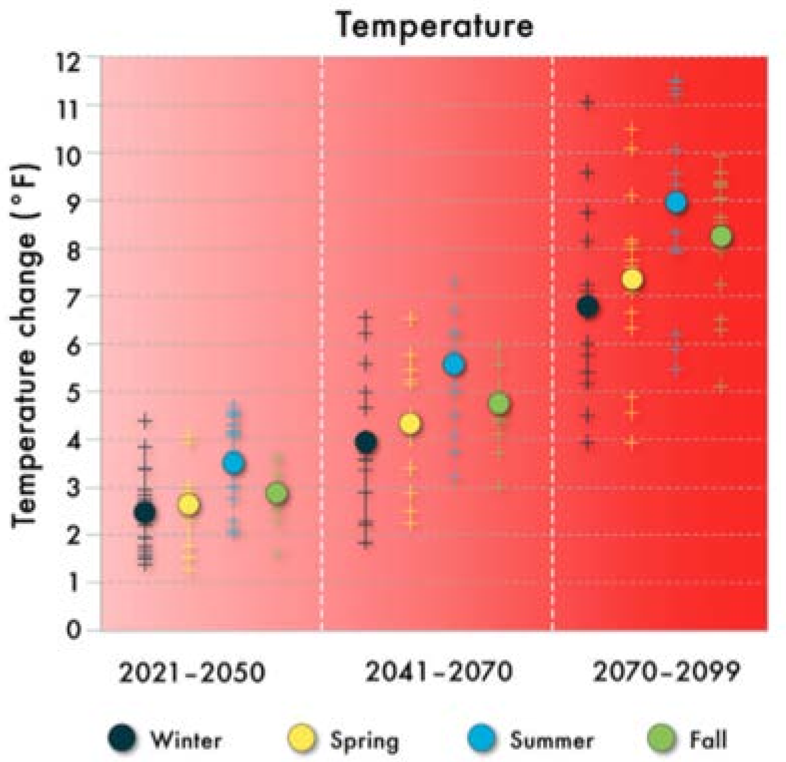


Figure 17. Projected change in average seasonal temperatures for the Southwest region in the high-emissions (A2) scenario. Plus signs are projected values for each individual model and circles depict overall means (Cayan et al 2013).

Temperature increases will also lead to an increased frequency of heat waves. As shown in Figure 18 a high emissions scenario projects increases in the annual maximum number of consecutive days when maximum temperatures are above a particular threshold, in this case, 95 °F (35 °C). Under a scenario of relatively high greenhouse gas emissions (A2), periods of maximum daily temperatures greater than 95 °F would increase an additional one to two weeks in San Diego County during the middle of this century, compared to the 1971-2000 reference period (shown by the blues and greens on the map in Figure 18).

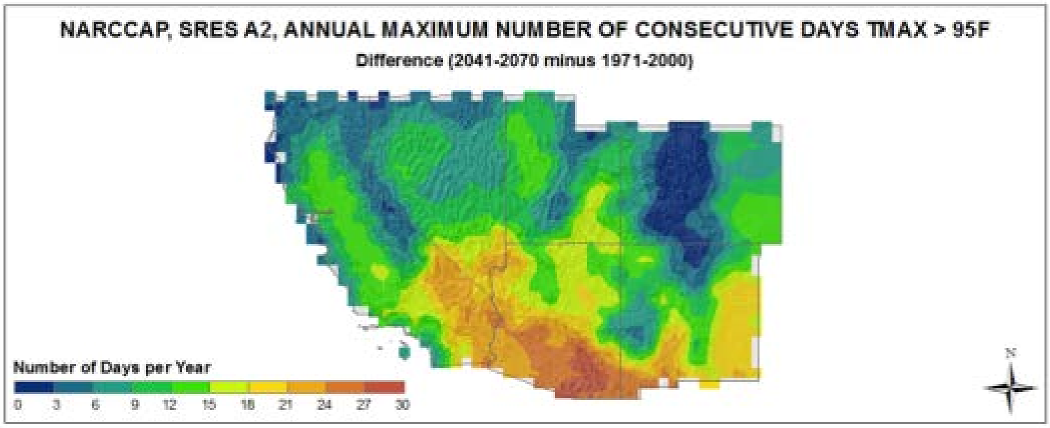


Figure 18. Projected annual mean difference in the number of consecutive days with a maximum temperature greater than 95°F (TMAX > 95°F) for the Southwest region (Kunkel et al. 2013). These fields are multi-model means from 9 NARCCAP regional climate simulations for the high (A2) emissions scenario.

Decreases in precipitation will also vary across seasons. For example, in Figure 19, declining seasonal precipitation under a high greenhouse gas emissions scenario (A2) will be more significant in spring than in winter. Total declines by the end of the century are projected to range from -10% to more than -30% in seasonal precipitation, compared to the 1901-1960 reference period. Wet regions will tend to become wetter while dry regions become drier. In general, the northern part of the U.S. is projected to see more winter and spring precipitation, while the Southwest is projected to experience less precipitation. This regional drying trend during these seasons will be driven in part by the jet stream's shift to the north, shunting storm systems – and the precipitation they deliver – away from the Southwest.

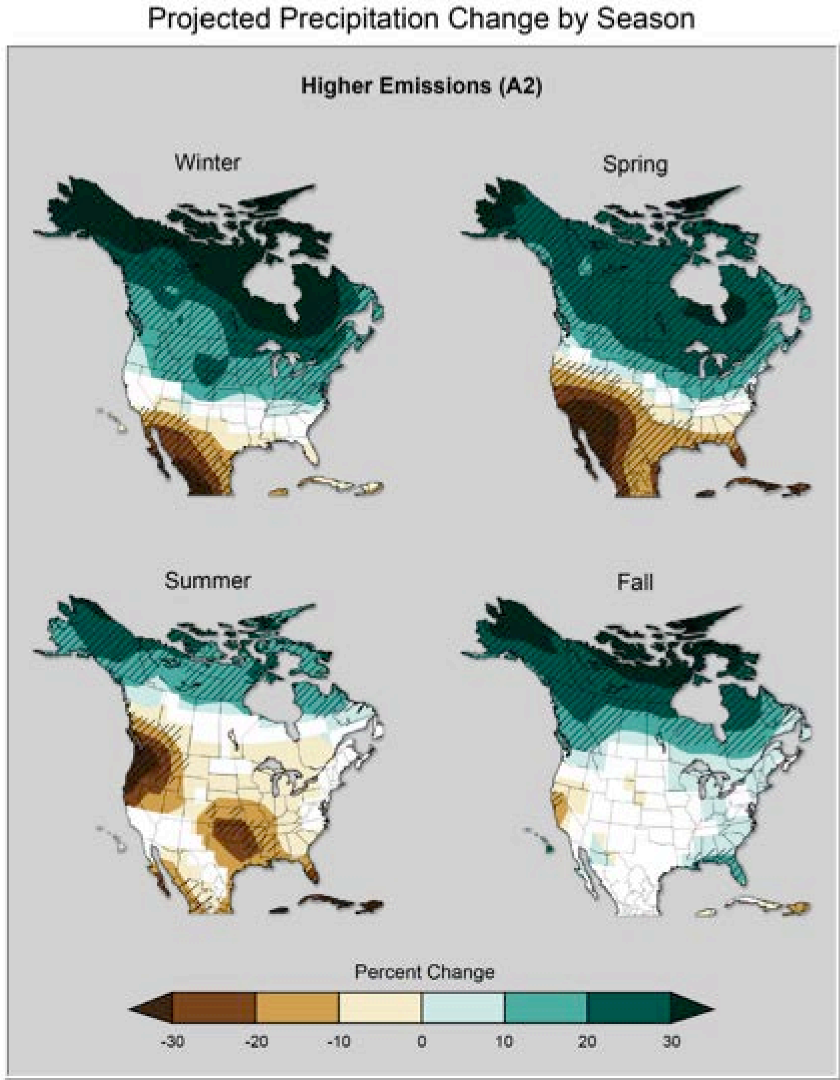


Figure 19. Projected percent change in seasonal precipitation for 2070-2099 (compared to the period 1901-1960) under the A2 emissions scenario. Green indicates precipitation increases, and brown, decreases. Hatched areas indicate confidence that the projected changes are large and are consistently wetter or drier. White areas indicate confidence that the changes are small. (Figure source: NOAA NCDC / CICS-NC, in Walsh et al. 2014. Data from CMIP3; analyzed by Michael Wehner, LBNL).

Though this scenario projects less total annual precipitation, a warmer atmosphere nonetheless has the capacity to hold more water vapor. This means that even while annual precipitation totals decrease, the rate at which precipitation falls may increase, leading to more intense rain or snow events, as well as potentially shorter return periods of heavy precipitation.

Heavy precipitation events are projected to double or triple in southern California by the end of this century, according to projections from the draft National Climate Assessment that were available at the time of the NBC workshop.

In an attempt to further spur such conversations, we also considered this first scenario in terms of possible related impacts to regional energy supply. Under warmer and drier conditions, we might anticipate increased evaporation, lower soil moisture, and increased water demand that reduce reservoir volume and hydroelectric production (Tidwell et al. 2013). This might be paired with lower plant efficiency, reduced transmission line, transformer, and substation capacity, increased energy demand, and a higher threat of wildland fires damaging energy supply infrastructure. To bring this hypothetical regional energy supply issue to the installation level, we presented information on the September 2011 blackout during which over one million customers in San Diego were without power on a hot day (FERC and NAERC 2012). Traffic became congested, schools and businesses closed, flights were cancelled, sewage plants shut down, and beaches closed. Although driven by operational error and not a weather event, looking back on the impacts of blackout events such as this one nonetheless help in the assessment of possible future risks to interruptions in energy supply.

Scenario 2 – Higher sea level and higher wave surge – Climate exposure

Key characteristics of Scenario 2:

- Sea level rise increases coastal erosion, flooding, and inundation (Table 7;Figures 20, 21)
- Sea level rise worsens impacts of El Niño events, high tides, and storms.
- Tidal wetlands and beaches accrete vertically, migrate landward, or become inundated with higher sea levels.

Table 7: Global mean sea level rise projections without regional adjustments used in the scenario of higher sea level and wave surge (Caldwell et al. 2013). Projection amounts do not include high tide or storm events.

	2030	2050	2070	2100
Sea-level rise	7 in	14 in	24 in	48in

The implications of sea level rise for coastal California cannot be understood in isolation from other, shorter-term sea-level variability related to El Niño-Southern Oscillation (ENSO) events, storms, or extreme tides that affect the coast. Historically, the greatest damage to coastal areas has occurred during large El Niño events (for example in 1940–41, 1982–83, and 1997–98) when short-term sea-level increases occurred simultaneously with high tides and large waves. The example in Figure 20 for San Francisco and similar variations would be expected for San Diego. In this figure, El Niño events raise sea level height by approximately one foot, on top of the existing sea-level rise that has increased about 8 in (~ 20 cm) along the California coast since 1900. As sea-level continues to rise, the impacts of future large ENSO events will be greater than those historical events of similar magnitude, possibly exposing coastal areas to the combined effects of sea-level rise, elevated sea levels from El Niño events, high tides and large waves from storms.

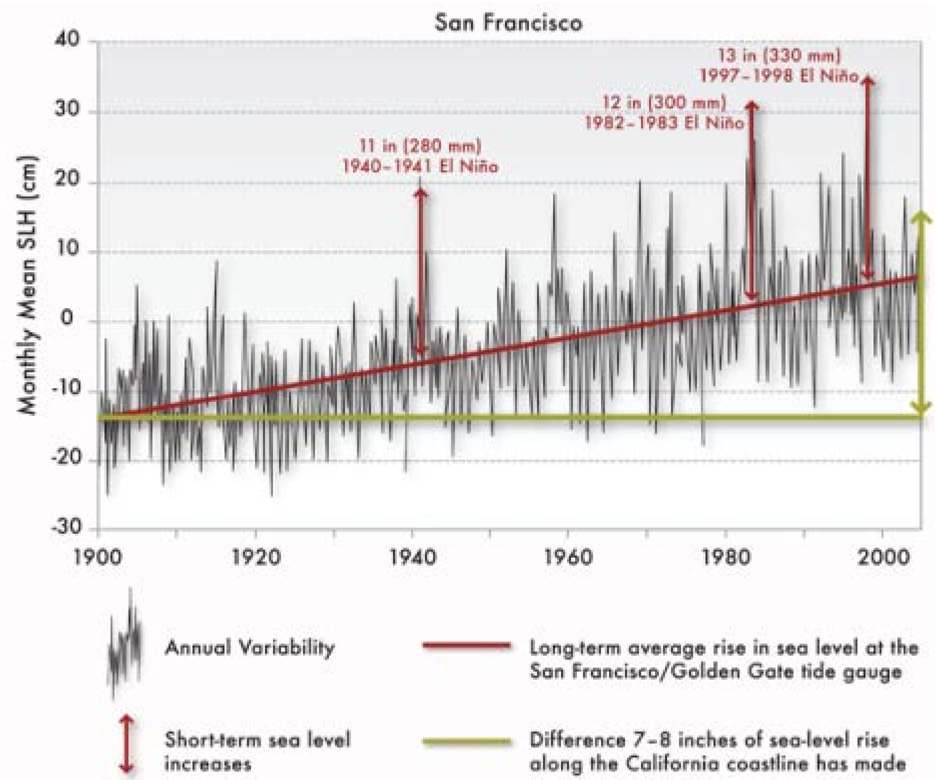


Figure 20. Sea-level rise and El Niño events (Caldwell et al. 2013).

To further compound the problem, any increased intensity and/or increased frequency of storm events will further aggravate the expected impacts from global sea-level rise, changing shorelines, near-shore ecosystems, and runoff. Storm events are inherently hard to model, due to the complexities of the coupled ocean-atmosphere system, leading to medium-low confidence in the trend towards increased intensity and frequency of storm events. However, there is medium-to-high confidence that storms coupled with rising sea levels will increase the exposure to waves and storm surges for many regions along the coast.

Figure 21. Left: flooding: Naval Air Station North Island (NASNI) – 1m sea level rise, 100-yr storm. Right: erosion: Naval Amphibious Base (NAB) – 1m sea level rise, 100-yr waves. (Based on work by Chadwick et al. (SERDP RC-1703).

Increasing coastal inundation will have material impacts on NBC's infrastructure and facilities. Figure 21 shows the potential coastal impacts with sea level rise for NBC units NASNI and the NAB. Under the conditions of 1 meter of sea level rise and a 100-year storm (left panel), potentially flooded areas on North Island are shown in blue, while infrastructure depicted on the map includes buildings in red and airfields in gray. Under the conditions of 1 meter of sea level rise and 100-year waves (right panel), areas of erosion at the Naval Amphibious Base are shown in yellow. For infrastructure, buildings are once again depicted in red, and beach training areas are in orange.

4.1.4. Assessing and prioritizing climate-related risks and opportunities

Using the decision-making criteria identified in previous sessions, groups of participants generated an inventory of risks associated with each future climate scenario. Where possible, participants were asked to identify key sensitivities and critical thresholds. As Figure 22 depicts, critical thresholds represent the boundaries between 'tolerable' and 'intolerable' levels of risk. Figure 22 demonstrates what can happen to a critical threshold in the future, when this threshold is based on a stationary (historic) climate. The critical threshold may for example be a maximum safe working temperature for training exercises, or the height of a sea wall. In a stationary climate, the threshold may be designed to tolerate infrequent breaches and its consequences. In a future climate, the threshold may be crossed more often and with greater intensity, now representing an intolerable level of risk. For continued successful operation, this would require

adaptation (blue area) in order to raise the acceptable threshold.

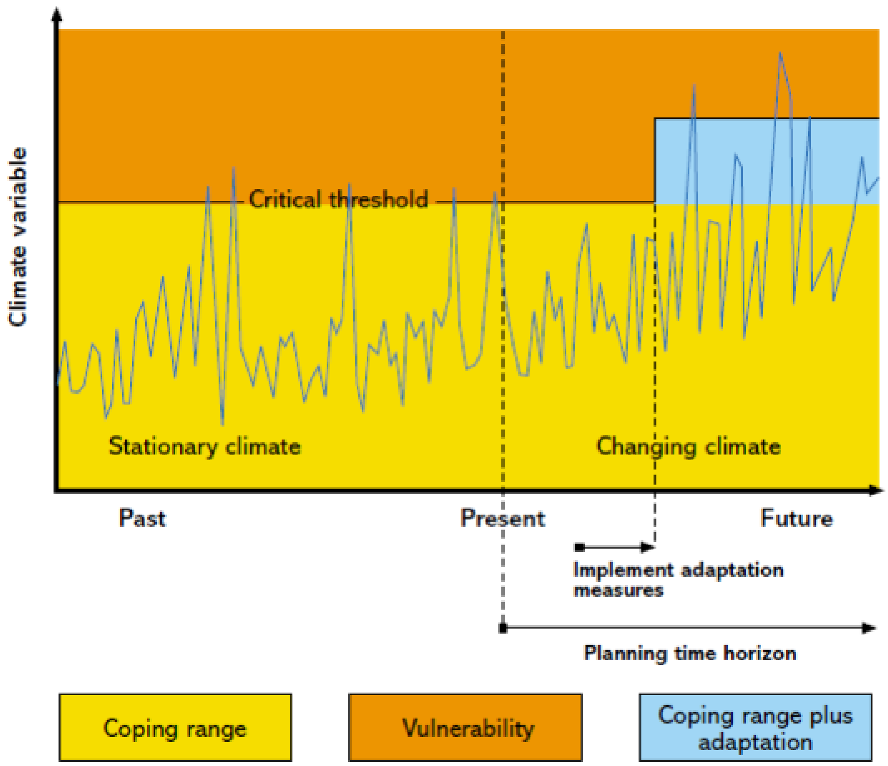


Figure 22. The relationship between coping range, critical threshold, vulnerability, and a climate-related performance criterion (Willows and Connell, 2003).

Participants prioritized risks, based on the following criteria:

- Critical thresholds may be breached
- Systems highly sensitive to changes
- Decisions with long-term consequences
- Where "failure is not an option"

Participants also examined risks that might cut across functional groups (i.e., operations, training, infrastructure, environment). Team members compiled and presented a list (Table 8) of all the groups' climate risks and participants voted on the priority risks identified across functional groups, in order to reach consensus on the issues deemed most critical to NBC.

Table 8: Climate risks for NBC identified during RC-2232 workshop discussions

Climate-related hazard	Risks to NBC's mission and success criteria
Sedimentation and erosion due to storm flooding	Safety and emergency response, drainage, sewers, contaminants, transportation, infrastructure, and Information Technology (IT)/communications
Erosion and flooding due to sea-level rise	Safety and emergency response, critical Infrastructure, waterfront assets, IT/communications
Land use and space allocation	Encroachment and conflicts with neighboring communities
Water availability	Conflict with other water users, Restriction on water use and disruption to mission essential services
Fire risk and erosion	Personnel safety, loss of training time
Energy security	Energy cost increases, power availability
Environmental management and compliance	Species migration, coastal habitats

4.1.5. Risk management

Workshop participants provided more detailed information on the current management of two top priority risks—(1) Sea Level Rise/Storm Surge/Erosion and Flooding, and (2) Availability of Water Resources for the Installation—and brainstormed on needs, barriers, and opportunities to improving management in the face of climate change, responding to the following questions:

- *Roles and responsibilities – who manages this risk?*
- *Existing guidance – what current plans are currently in place for this risk?*
- *Existing controls – what is the process for dealing with this risk?*
- *Needs – what informational/human resources/financial resources/monitoring is needed*
- *Barriers – what is getting in the way, or may get in the way of responding?*
- *Opportunities – are there benefits to acting now?*

A summary of remarks raised repeatedly in discussions of these two key issues are included in Table 9, below. With respect to the combination of sea level rise, storm surge, and coastal flooding: (a) roles, responsibilities, and guidance were straightforward; (b) the process doesn't allow planning for future impacts; (c) there are needs for data and standardized predictions, as well as improved coordination with beyond fence line agencies; (d) budgets for long-term planning and communication bottlenecks were seen as barriers, and (e) the key opportunity is from climate change initiatives in the region, which can support NBC initiatives.

With respect to water availability: (a) NBC is dependent on beyond the fence line water sources; (b) thus, guidance and process stems from local public works departments; (c) participants noted needs for improved precipitation and hydrologic data and forecasts; (d) barriers included infrastructure repair and lack of support for a policy of water self-sufficiency; (e) whereas there are opportunities to develop self-sufficiency (especially in emergencies) and for improved water conservation.

Table 9. NBC Risk management summary related to sea level rise-storm surge-and flooding, and water resources risks. Based on workshop discussions, May 2013.

Category	Sea Level and Flooding	Water Availability
Roles and Responsibilities	• Higher level and regional level engineers determine long-term thresholds • Beyond acceptable risk levels, gaps are mitigated by using emergency resources • Emergency operations center gathers information and prioritizes responses	• NBC is dependent on local water districts, at the “end of the pipe”
Existing Guidance	• We accept risk: we don’t invest in worst case scenarios • Standardized incident command management and tools • Policies are installation-specific	• Limited storage; thus, curtailing services • Coordination with beyond the fence line community and resource managers
Existing Process	• Current building codes; we cannot plan to future impacts. • Current mission and future mission guide plans for new infrastructure • For emergencies: prompt interaction with neighboring municipalities	• Local public works monitors NBC supplies
Needs	• Standardized impact prediction models (in response to variability among models for 100-year floods) • Precise sea level elevation data and maps • Early warning • Federal policy across agencies, for consistent messaging • Improved coordination with agencies beyond the installation fence line	• Improved water supply forecasts • Improved precipitation and local rainwater infiltration forecasts and data – matched to scale and format

	• Earmarked financial resources	
Category	**Sea Level and Flooding**	**Water Availability**
Barriers	• Limited budget, with short-term focus • Improved communication of climate change challenges to the "flag" level • Improved communication with civilian entities • Climate change skepticism	• Improved communication with U.S. Navy hierarchy regarding the need for NBC water supply self-sufficiency • Re-examine water allocation and water priority agreements • Funding to repair water infrastructure (~20% water loss through water lines within the installation)
Opportunities	• The citizens of San Diego want to address climate change challenges • Framing: DoD concerns with regard to climate change and security provides credibility • Relationships with other jurisdictions	• Nuclear aircraft carriers can desalinate and provide water and can serve as emergency power generators • Water conservation to address 20% water loss

4.1.6. Risk assessment results

Using the risk assessment methodology described in Section 3.______, and using input from participants in our May, 2013 risk assessment workshop, we performed a high-level (installation-wide) semi-quantitative assessment of climate-related risks and opportunities for NBC. We assessed future risk in the absence of further adaptation action, based on current and projected future climate variability and change. We discuss selected key risks, below, based on the seven high priority risks identified by workshop participants (Table 9 above); we note whether risks relate to inland or coastal facilities, but not at the level of individual NBC units. A full inventory of risks and assessed risk levels is available in Appendix C and Appendix F.

The five key NBC direct and indirect climate-hazard factors examined in the risk assessment include:

1. Wildfires caused by warmer and drier conditions;
2. Flooding and associated erosion due to more frequent heavy downpours of rain;
3. Extreme high temperatures;
4. Water scarcity caused by decreased precipitation; and
5. Enhanced flooding caused by sea level rise, increased wave heights and storm surge.

The direct climate impacts affect the following mission-related NBC activities:

- Mission Essential Infrastructure, Assets and Services
- Force Protection and Safety
- Environment and Regulatory Requirements
- Local Communities and Public Relations

The direct impacts of climate frequently have interconnected effects, or cascades of impacts, which we explore, in the following sections devoted to training and operational readiness, and emergency preparedness. Figure 23 illustrates an example of linked effects.

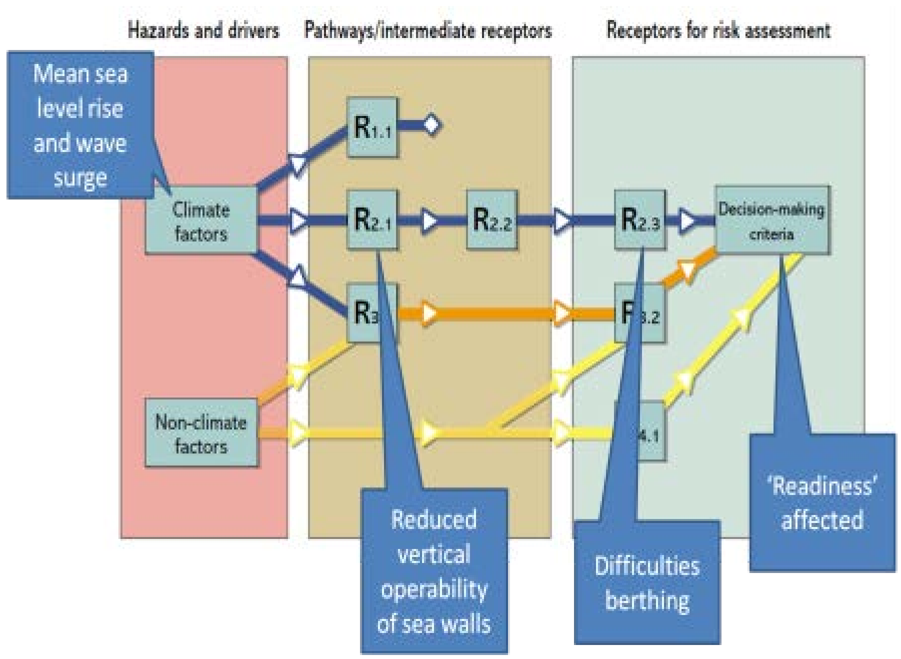


Figure 23. The pathway linking hazards (climate and non-climate factors), receptors and decision criteria. The blue boxes show an example for NBC.

From our assessment, we determined the following list of top-rated climate-related risks for NBC. These cover the spectrum of success criteria identified by personnel (Table 9 above). We include the risk reference identifiers will be proceeded by "risk ref" followed by an alphanumeric code, such as TO2, from the full risk inventory in Appendix C. We provide an excerpt of the 28 page risk inventory (Table 10), to illustrate a small portion of the NBC results of the semi-quantitative risk assessment method described in Sections 3.2 and 3.3. The risks have been ranked based on their risk value, from high to low. Opportunities are grouped at the end of the table.

Top Risks.

- Increased competition for resources may result in restricted access to supplies for NBC and potential conflict with other local users (risk ref. F06);
- Changes in the use and availability of land may restrict NBC's training mission, with consequences for operational readiness (risk ref. T02 / T14);
- Increasing NBC's resilience to incremental climate change and extreme events will result in increased capital, operational and maintenance expenditure and planned budgets may be exceeded (risk ref. T25 / F04);
- Increased risk of wildfires that damage / destroy remote training grounds and buildings, and cause wider natural environmental and hydrologic damage (risk ref. F03);
- Asset and equipment underperformance due to overheating and insufficient cooling, leading to loss of mission essential services (e.g. IT, power and communications) and operational readiness (risk ref. OP07 / F15 / F02 / F09);
- Erosion of inland sites due to more frequent heavy downpours of rain, causing environmental degradation and risk of further ground instability, especially following severe wildfires (risk ref. F26);
- Increased risk of adverse effects to air and water quality due to wild-fires, with associated impacts for human health and social functioning (risk ref. EN05 / EN10);
- Flooding and erosion of transportation routes due to more frequent heavy downpours of rain resulting in disruption to training and operations, and comprised emergency response (risk ref. F27 / OP21);
- Aircraft underperformance due to overheating with the loss of training and operational readiness (risk ref. OP05); and
- Heat stress for personnel due to more frequent extreme high temperatures, leading to increased rotation and loss of training time (risk ref. OP12).

Risk reference codes relate to the workshop break-out groups, where the risk was originally identified: O = Operations; F = Facilities; T = Training; and EN = Environment. Risks and opportunities have been linked to specific NBC environments (coastal or inland), where relevant, or labeled as cross-cutting (Table 10).

Table 10: **Excerpt of climate risks and opportunities for NBC**.

Risk ref:	**Climate driver (cause)**	**Process**	**Consequence**	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots)	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	**Risk**
T25 / F04	Incremental climate change	causes increased costs	with the consequences that planned budgets may be exceeded	XC	4	2	10	0	0.5	5	0	2	0	8	12.5
F03	Warmer and drier conditions	causes increased risk of wild fires	with the consequence that remote training grounds and buildings are damaged / destroyed, and wider natural environmental damage occurs	I		2	2	2	0.5	5	1	2	2	8	12.5
OP19	More frequent heavy downpours of rain	causes flooding of sewer systems and lift stations	with the consequence that mission essential services are compromised	XC	3	2	1	2	0.5	5	0	1	1	8	3.75
T10	More frequent extreme high temperatures	causes heat stress	with the consequence of loss of training days	XC		2	10	0	0.1	5	1	0	1	8	2.5
EN15	Incremental climate change	cause changes in the riparian / coastal / marine environment	with the consequence that environmental management costs increase	XC	5	2	10	0	0.1	5	0	2	0	8	2.5

Opportunities. We identified a number of climate-related opportunities for NBC, using the semi-quantitative risk assessment. Top opportunities relate to raising NBC's profile as a leader on adaptation, and working collaboratively with other jurisdictions, organizations, and agencies in the San Diego area to reduce vulnerability to the risks posed by climate change.

- NBC has the opportunity to position itself as a leader on the issue of adaptation to physical climate change by setting appropriate benchmarks and frameworks (risk ref. EN31);
- NBC has the opportunity to work more closely with local administrations and communities to improve the climate-resilience of the San Diego area (risk ref. EN23; T16); and
- NBC can mitigate the risks posed by a changing climate, by introducing necessary adaptation measures (e.g. water harvesting; risk ref. EN13) based on an improved understanding of the relationship between asset performance and environmental conditions.

4.1.6.1 Direct climate impacts to mission essential infrastructure, assets and services

Climate changes (e.g., higher temperatures, more intense and frequent extreme weather events) are likely to create a number of technical risks for NBC's existing infrastructure and essential services, such as energy, water availability and wastewater treatment and disposal. Infrastructure could be damaged or underperform because design criteria are based on historical climate conditions; these criteria may no longer be well-tuned to future climate conditions. Individual assets may not be resilient to a broader range of climatic conditions, and normal asset wear and tear is likely to increase, with associated increases in repair and maintenance costs (discussed at length, below). There is also the potential that the lifespans of assets will decrease, with associated capital costs for replacement or modification. Third-party infrastructure on which NBC depends (e.g., energy, water, and transport) will also be impacted by climate change, causing operational and logistical challenges. We discuss the key climate-related risks to mission essential infrastructure, assets and services in terms of the five primary climate hazards outlined at the start of Section 4.1.6.

Asset integrity and/or requirement for modifications.
For a range of assets, integrity is likely to be impacted by climate change over time, with an increased requirement for modifications and retrofitting, which has associated financial implications, including the cross-cutting issue of insurance. As present-day fixed asset damage costs increase, and awareness of weather- and climate-related impacts increases, insurance companies are re-assessing the policies they offer; the upshot is that as insurance premiums increase, some assets become un-insurable and NBC takes on extra risk and financial burdens due to reduced cover.

Wildfires. In the most severe events, wildfires have the potential to cause extensive and irreversible damage to assets and infrastructure. Wider geographical distribution and increased frequency of wildfires as temperatures rise pose a threat to NBC's operations and assets in regions already susceptible or vulnerable to this hazard (e.g. Camp Michael Monsoor (CMM)

Mountain Warfare Training Facility, San Clemente Island, Remote Training Site at Warner Springs (SERE) and Camp Morena). Direct damage to assets, whether through destruction or increased requirement for cleaning following ingress of carbon particles, has the potential to cause significant capital and operational expenditure costs, together with cascading consequences for operational and training readiness due to downtime (risk ref. FO3; FO2; OP2). As an example, the highly destructive 2003 and 2007 San Diego wildfires resulted in Navy staff death, operations halted, destruction of endangered species habitat, soil erosion and sediment build up, and other impacts.

Flooding. Fluvial flooding has the potential to cause significant damage to infrastructure, assets and the surrounding environment, which will likely result in operational downtime and a need to expend additional capital. Flooding, from rivers and estuaries, and surface water sources, can occur due to incremental changes in climate (e.g. progressive melting of land-based snow and ice raising global sea levels) or through extreme weather events (e.g. intense storms and exceedance of infrastructure drainage capacity). In extreme cases, flood events can cause significant erosion and slope failures (risk ref. OP09). Bank erosion on the Tijuana estuary side is already threatening the landing platforms. NBC is also vulnerable to cross-border dumping of waste, compounding the impacts of extreme rainfall by causing localized restrictions in flow, elevating river levels and redirecting flow.

The majority of the flood-related risks identified at the workshop related to surface water flooding. This is generally a more complex problem than fluvial flooding and more difficult to predict, as the location and extent of flooding depends on heaviness and duration of rainfall, as well as the adequacy of drainage systems. As a result, warning lead times tend to be much shorter. Assets and locations particularly at risk from surface water flooding include:

- large areas of hard standing (e.g. roads and airfields; risk ref. OP20; OP11),
- underground infrastructure (e.g. energy, IT and wastewater systems, lift stations; risk ref. F10; F12; OP19), and
- areas with storm water systems that are not designed to manage short duration intense rainstorms (e.g. beachfront car-park at the Silver Strand Training Complex; risk ref. (FO1; F24).

The consequences for NBC are that assets and infrastructure may be damaged or rendered temporarily inoperable, which has cascading consequence for operational and training readiness (risk ref. F25; T03). This risk is further compounded by a lack of baseline knowledge or maps of the underground cabling routes, which increases the installation’s vulnerability to flood-related risks, from river, surface water and groundwater (risk ref. F16).

Sea level rise, coastal flooding and saline intrusions. Flooding of coastal assets can result from a number of mechanisms, including:

- incremental increase in mean sea level, due to the thermal expansion of sea water, melting of land-based snow and ice and changes in ocean circulation patterns;
- increased wave heights, due to storm activity and wind fetch; and
- storm surge processes, resulting from the development of intense low pressure systems offshore.

NBC's location makes coastal flooding particularly relevant. Any damage to assets and the surrounding environment is likely to result in operational downtime and ultimately, the requirement for additional capital expenditure, whether that is for maintenance or replacement (risk ref. OP27; EN26), or costs associated with coastal protection (e.g. beach replenishment; risk ref. OP25). To increase the protection of NBC's coastal infrastructure and assets or to relocate the facilities inland would involve significant capital costs. Flooding of coastal assets and infrastructure has the potential to render them inoperable. For example, increased stress on the vertical operability of docks may create challenges for the loading and unloading of ships (risk ref. F37), and flooding of power systems may create supply failures (risk ref. F30; F31). Corrosive saline floodwater typically causes more damage than freshwater. Infrastructure and asset types identified as being particularly at risk from coastal flooding include:

- Critical infrastructure (e.g. Emergency Operations Centre) (risk ref. F35)
- Transport (e.g. roads on the Silver Strand) (risk ref. OP36; OP25)
- Water supply and wastewater (risk ref. OP32; F35)
- Operational runways and landing lights (risk ref. EN20; F36)
- Piers, harbors, sea walls and berthing areas (risk ref. OP26; OP27; EN26; F38)
- Underground infrastructure (e.g. power sub-stations) (risk ref. F30; F31)

Moreover, sea level rise and higher wave surge have the potential to create saline intrusions, whereby the groundwater level rises and becomes increasingly saline. This may affect the integrity of submerged concrete structures and piles, and particularly those that have reinforced steel (risk ref. F33) and may result in critical buildings being at operational risk (e.g. Fleet Area FLATSFAC communication building; risk ref. F34).

Extreme high temperatures. Long periods of intense heat or drought can lead to soil settling effects beneath key structures and roads. More extreme temperatures alone can accelerate road deterioration; for instance, roads made from a bituminous hot mix are susceptible to "bleeding" in high temperatures, a process whereby the bitumen seeps through the aggregate to the road surface. This risk may affect asphalt runways shoulders and roads at NBC, which will render them inoperable and affect training and operational readiness (risk ref. F21). Temperature stress can cause lateral buckling on surface pipelines and other linear infrastructure. Although often limited in extent, this can lead to operational disruption.

Asset performance

For existing, un-adapted assets, climate change is likely to reduce the efficiencies of assets and thus cause disruption to operations. Additional capital expenditure may also be required to modify existing assets so that they can cope with new climatic conditions.

Extreme high temperatures. Increased air temperature is widely known to cause decreased efficiency (and potential failure) of power generation and transmission, air-conditioning, process and electrical equipment (e.g. turbines, fin-fans, transformers and switches) (risk ref. F02; OP07; F15; F09) and aircraft (risk ref. OP05). Underperforming assets will ultimately mean downtime in equipment use and potential power supply failures, which may lead to the requirement for asset modification and therefore capital expenditure. Higher temperatures also have the potential to create additional demand for power and water, which the existing assets may not be able to

provide effectively or efficiently. This will ultimately lead to increased operational costs (F05) and affect the provision of mission essential services (OP18).

Third party infrastructure and supply chains

Third-party infrastructure on which NBC depends (e.g. transport, energy, water, ICT) are likely to be impacted by climate change, causing operational and logistical challenges for the installation. A variety of climate hazards have the potential to cause damage and disruption to third-party infrastructure and their supply of services, including sea level rise and higher wave surge (risk ref. OP36; T21), warmer and drier conditions (risk ref. F13; F14; T05), more frequent extreme high temperatures (risk ref. OP08) and storm events (risk ref. F11).

In a future resource constrained world, NBC may face increased restrictions on energy and water use, due to the fact that NBC is a large user in the San Diego area. Under extreme conditions, for example power or water shortages, NBC's operations may be impacted (e.g., taking ships off the grid; risk ref. OP08; reducing water supply; risk ref. F13; F14; T05). This may lead NBC to invest in costly and energy-intensive alternatives, such as desalination plants (risk ref. F08).

NBC also relies on long supply chains and distribution networks, meaning that there is added indirect exposure to climate change impacts through their suppliers of goods and services. Climate-related risks include transport delays and interruptions, logistics and supply failures, and commodity price vulnerability (risk ref. F43).

4.1.6.2 Direct climate impacts to Force Protection and Safety

There are a number of climate-related risks for force protection and safety which may change in the future, resulting from hazards including wildfires, extreme high temperatures, sea level rise and storm surge. These are grouped under the headings of installation perimeter and patrol, and personnel health and safety.

Installation perimeter and patrol

NBC has a controlled and secure perimeter, which is essential for force protection and anti-terrorism. Several climate hazards may cause protection and security issues, as outlined below.

Wildfires. These events may change the physical perimeter of the installation and cause patrol issues, through poor visibility, for example (risk ref. OP14).

Sea level rise and higher wave surge. Flooding and erosion associated with these hazards may cause difficulties in maintaining a perimeter around installations (risk ref. OP38), access problems to critical areas (risk ref. OP37), and over the longer term, an expansion of the in-water perimeter and patrol area (risk ref. OP39).

Extreme high temperatures. More frequent temperatures extremes have the potential to cause heat-stress related risks for military dogs, meaning that they are unable to perform their duties (risk ref. OP13).

Personnel health and safety
Climate change is unlikely to create any new personnel health and safety issues for NBC, but has the potential to increase the *frequency* of occurrence and *severity* of consequence. Generally, increased frequency and severity of extreme weather events may lead to critical safety thresholds being breached (risk ref. T11), an increased need for personnel training and capacity building (risk ref. T23) and changes in current warning systems and planning procedures (risk ref. T24; OP16). Specific risks are discussed in more detail below, divided by climate hazard.

Wildfires. Wildfires have the potential to have devastating consequences, including fatalities in the most severe events (risk ref. F23). Furthermore, air pollution associated with fires can pose a significant threat to human health and social functioning (risk ref. EN05; EN10; T09; OP15).

Flooding. Floods have the potential to directly cause injuries and fatalities, through the movement of flood water and debris. Associated indirect consequences include contamination of water courses (e.g. Tijuana River runoff), which may affect health and safety through water quality issues (risk ref. OP17).

Sea level rise and higher wave surge. Coastal flooding, where the lead-in times are short, for example due to storm events, have the potential to directly cause injuries and fatalities, and lead to increased evacuations and a shift to mission essential only personnel (risk ref. T22; T26). Coastal flooding also can mobilize contaminants in soil, posing a threat to personnel and civilian health and safety (risk ref. OP33).

Extreme high temperatures. More frequent extreme high temperatures have the potential to cause heat-stress related risks for personnel, which in extreme case can cause fatalities (risk ref. T31). To protect personnel against this risk, the Navy has strict policies regarding work / rest cycles (when temperatures rise above 90°F, 45 minutes rest for every 15 minutes work). If such high temperatures become more common under a changing climate, there is the potential that training time will be lost and there will be an increased rotation of personnel (risk ref. T10; OP10; OP12).

4.1.6.3 Direct climate impacts on the environment and regulatory requirements

NBC fully recognizes environmental stewardship is an integral part of productivity and providing quality services across the installation's activities (Naval Base Coronado website 2017). In recognition of this responsibility to NBC's sailors, customers, civilian personnel, neighbors and others, NBC is committed to (Naval Base Coronado website 2017):

- Being an environmentally responsible neighbor to ensure public health and safety and protection of the environment;
- Preserving significant aspects of the natural and cultural environment;
- Using sustainable resources to modernize facilities and shore-side infrastructure;
- Conserving natural resources by reducing, reusing, and recycling materials; and purchasing products made from recycled materials;
- Developing and improving operations and technologies that minimize waste; preventing air and water pollution; minimizing health and safety risks; and disposing of waste safely and responsibly;
- Ensuring the responsible use of energy and water, including conservation and improved

efficiency;

- Sharing appropriate pollution prevention technologies, knowledge and methods;
- Participating in efforts to improve environmental protection and understanding in local communities;
- Adhering with applicable environmental federal, state, and local regulations, and Department of Defense, and Navy policies; and
- Ensuring their policy is communicated to all military and civilian personnel, and contractors to encourage continual improvement within the region.

Climate change has the potential to directly impact the local environment, with associated consequence for NBC's environmental stewardship and regulatory requirements (risk ref. EN15). For instance, incremental climate change could directly affect endangered species or cause changes in their behavior leading to their migration into or away from land owned and protected by NBC (risk ref. EN01; TO6). This has the potential to result in increased management costs for environmental compliance (risk ref. EN15), issues associated with insurance (risk ref. EN18) and potential legal challenges (risk ref. EN17). Discussion of the main climate-related impacts on the environment and regulatory requirements is divided by the primary climate hazards previously identified.

Wildfires. Wildfires have the potential to damage and destroy large areas of woodland and scrub vegetation. Under a changing climate, increased frequency and intensity of wildfires may result in habitats being significantly changed and / or lost, with the consequence that NBC's environmental management efforts escalate (risk ref. EN04).

Flooding. More frequent heavy downpours of rain have the potential to alter contaminant pathways, with pollutant run-off from land, properties or equipment into surface and ground water sources (risk ref. F22). Furthermore, changes in ground conditions (including subsidence, heave and landslips; risk ref. F26) could create new pathways for contaminants, which would then flush through into water courses during heavy rainfall (risk ref. EN02). Increased migration of contaminants may represent an additional compliance risk. The (re)mobilization of contaminants in fill, as well as unexploded ordnance (UXO), is a current vulnerability, especially on the bayside of the NAB. Flooding of historic properties and archaeological sites may also create environmental management challenges for NBC, with additional resources being needed for cultural work (risk ref. EN14; EN03).

Aridity. Warmer and drier conditions may cause changes in the local environment, including changes in soil moisture, vegetation cover and the distribution and numbers of non-native wildlife / invasive species (risk ref. EN11; EN08; EN07). These changes may be beneficial or detrimental to the environment, creating management opportunities or challenges for NBC.

Sea level rise and higher wave surge. Sea level rise and higher wave surge may cause changes in the coastal and marine environment creating environmental management challenges and compliance issues for NBC (risk ref. EN30). This could be both positive (e.g. the restoration of wetlands, with associated impacts on water quality; risk ref. EN24) or negative (e.g. erosion of long shores; risk ref. T19). These changes will have associated consequences for the species living in these coastal habitats (e.g., Eel grass, nesting birds) (risk ref. EN21 / EN22 / T28). There is the potential that NBC may not be able to meet their obligations under the Endangered

Species Act (risk ref. T17) and to the Coastal Commission (risk ref. T20).

Saline intrusion and changes in groundwater levels may also create new source-pathway-receptor relationships, increasing pollution risks associated with contaminated land (e.g., waste storage areas) (risk ref. EN28; EN29; OP34). Sea level rise and higher wave surge may also cause flooding and exceedance of storm water drainage systems, with the consequence that environmental regulatory compliance is compromised (risk ref. EN19). Sea level rise and the flooding of coastal assets (discussed in more detail in Section 0) may also lead to an increase in regulatory activities (risk ref. EN27). For instance, discharge thresholds may be exceeded, due to higher concentrations of pollutants in run-off (e.g. from roads and runways).

4.1.6.4 Direct climate impacts on Local Communities and Public Relations

NBC is intimately connected to the local communities surrounding the installation and its operations can result in impacts, both positive and negative, in many ways. The benefits NBC aims to bring to local people include jobs, contracting and business opportunities and social investment. Furthermore, NBC works hard to manage any negative effect on the livelihood, health, safety, lifestyle, security and economic development of local communities and maintain social license to operate.

Beyond the fence line risks. Climate change is likely to impact San Diego and its people, and there are a number of ‘beyond the fence line’ risks that will have implications for NBC’s operations and reputation within the region. This can be both positive, if NBC is able to work more closely with local administrations and communities to improve the climate-resilience of the San Diego area (risk ref. EN23; T16), or negative, if NBC is viewed as being culpable for environmental degradation or takes risk management actions that are viewed as detrimental to the local area (risk ref. EN16). An example of the latter could be NBC not fulfilling beach nourishment requirements (risk ref. T18). Key drivers include changes in water resource availability (risk ref. T04), changes in land use and space allocation (e.g. due to sea level rise and coastal erosion; risk ref. T02; T14) and the migration of people due to natural disasters (risk ref. T01). The resulting consequence could be that NBC is required to further support neighboring communities and communicate more effectively, with additional resources allocated to public relations activities (risk ref. T15).

4.1.6.5 Cascading consequences for Training and Operational Readiness

Of the risks discussed above, a high proportion have interconnections and cascading consequences for NBC’s primary and overarching success criteria for training and operational readiness. These are explored in more detail below, again divided by primary climate hazard. Generally, a changing climate (both incremental climate change and extreme events) has the potential to make the civilian population more risk averse, and as a consequence the number of tenants brought in may decline and training days may be lost (risk ref. T13).

Wildfires. As described above, wildfires have the potential to cause significant damage and disruption to assets, training grounds (e.g., Camp Michael Monsoor (CMM) Mountain Warfare Training Facility, San Clemente Island, Remote Training Site at Warner Springs (SERE) and Camp Morena), third party infrastructure (e.g., communication routes) and the wider natural

environment, which will ultimately equate to a loss of training time and operational readiness (risk ref. F03; F20 / OP2; T12). This may be due to the direct loss of operating infrastructure and assets, diversion of resources to evacuation and fire-fighting (risk ref. OP01), limits to ordnances (OP03) and restrictions to troop movements between installations / regions (risk ref. OP04).

Flooding. As discussed above, flood events and associated impacts on assets, facilities and transport routes can render assets inoperable and prevent staff access, therefore resulting in a loss of training time and operational readiness (risk ref. F27 / OP21; OP09; OP20 / OP11; F25 / TO3).

Sea level rise and higher wave surge. Sea level rise and higher wave surge and the associated flooding and erosion (e.g., Silver Strand, Naval Outlying Landing Field, Imperial Beach) have the potential to make assets and utilities inoperable and/or damaged, which will ultimately affect training and operational readiness (risk ref. OP24 / T27; T21; F29;). A specific example quoted at the workshop was flooding of Runway 36, which affects aircraft operations, training and readiness (risk ref. F39). Equally flood-related damage and disruption to third party transport infrastructure (e.g. roads in the former Spanish Bight; Silver Strand Highway) will affect traffic and staff accessibility, and thus training time (risk ref. T29; F40). Environmental changes, particularly species migration may cause NBC to review current and ongoing operational and training activities (risk ref. EN21; OP28; OP06). Finally, on a larger scale, loss of land due to coastal inundation and erosion may mean that the development of new training and operational facilities is constrained and expansion of NBC's capacity is not realized (risk ref. F28).

Extreme high temperatures. As discussed above, more frequent extreme high temperatures may cause increased incidents of heat stress for personnel, with the consequence that training time is reduced due to compliance with work-rest cycle (when temperatures rise above 90°F, 45 minutes rest for every 15 minutes work) (risk ref. OP10). When multiplied by the number of personnel affected by this code of practice, this risk has the potential to significantly affect training time.

4.1.6.6 Cascading consequences for emergency preparedness

Diversion of resources. Several climate hazards and their associated impacts have the potential to divert NBC's resources aware from mission objectives and training needs, including extreme events (e.g. flooding, sea level rise) (risk ref. OP23; OP31). Increased frequency and magnitude of such events under a changing climate may mean that costs associated with emergency preparedness increase (e.g. purchasing more equipment and conducting more frequent drills). Finally, due to the installation's size and expertise, surrounding communities may look to NBC for leadership and emergency response services (e.g., debris removal), which ultimately diverts staff time and resources away from training and operational tasks.

4.1.7. Climate and sea level rise

Based on our workshop interactions with NBC personnel, their workshop prioritization of top risks, and the results of our expert-based risk assessment, the combination of sea level rise, coastal flooding, and storm surge was identified as a top risk—with implications for transportation, training, infrastructure, force protection and safety, and groundwater quality. Our interactions to apply scientific findings to risks and adaptation decisions was mediated by the

work of Chadwick et al. (2015), through a SERDP-funded project (RC-1703) devoted to assessment of the impact of sea level rise at NBC and other installations. Consequently, we worked with personnel to apply information from Chadwick et al.'s exhaustive study. In 2014, NBC personnel informed us that interpretation of Chadwick et al.'s 554 page report would be valuable; they also mentioned that briefing materials on sea level and storm surge effects, in the context of the upcoming 2014-2015 El Niño event, would be a valuable climate service.

In July 2014, we sent NBC a one-page brief offering to develop and provide a "translational" information product that integrates results from the report by Chadwick and colleagues with the climate-related risks identified in the work by the University of Arizona and Acclimatise. We indicated that the information product would follow the initial approach presented during our webinar, and cover additional identified climate-related risks and related examples. Also in July 2014, we sent NBC a one-page brief offering to develop and provide a geospatial analysis that identified vulnerable assets at North Island, Naval Amphibious Base, and Silver Strand Training Complex North and South in the context of the anticipated 2014-2015 El Niño event. In August 2014, we sent NBC a multiple-page brief updating the changes in conditions related to the 2014-2015 El Niño event.

In follow up communication with NBC personnel, they acknowledged that current and projected future sea level rise, and imminent coastal erosion, continues to be an area of concern. NBC has been inundated with information and studies regarding sea level rise and coastal erosion. They have acted on this issue to actively adapt to climate change, in the following ways:

1. They now work regularly with Scripps Institution of Oceanography on coastal erosion assessment, using drone flights to perform live monitoring of protection assets, such as berms.
2. NBC has applied climate change sea level rise information to their Environmental Impact Statements.
3. They have moved new construction to higher sites, and have aimed to avoid certain ecosystem features (e.g., vernal pools) that may be adversely affected by the combination of climate changes and infrastructure construction.
4. They have also addressed concerns with regard to vulnerabilities of some coastal buildings and parking lots.
5. Climate change is included in their recently drafted master plan, through strategies such as: (a) addressing the exposure of the lower floors of buildings to the potential effects of sea level rise and storm surge flooding; (b) taking into account longer time scales in site approval processes for construction.

NBC personnel mentioned that important climate services to aid in addressing sea level rise concerns could include:

1. Scientist review of plans and strategies for addressing climate, sea level rise, and coastal protection
2. Periodically reviewing coastal erosion baselines and changes
3. Fact sheets on recent trends
4. Ongoing communication, through reports, and possible collaboration on grant-funded projects to address installation-specific concerns

4.1.8. Climate and fire risk

We followed up our risk assessment activity with a Tier 2 and 3 assessments of wildfire danger for NBC's inland facilities, Camp Michael Monsoor (CMM) and Camp Morena (CM). Despite the lower rank of wildfire among climate-related risks, NBC personnel preferred detailed climate risk assessment and adaptation climate services on wildfire, due to imminent threats to infrastructure, their lack of expertise in climate-fire ecology, and the relative lack of research and outreach attention to this particular risk—relative to research and outreach on sea level rise and coastal flooding. The overarching goal of this case study was to better understand the fire-related risks posed by projected future climate conditions through studies of threats to inland training facilities at Naval Base Coronado in relation to the greater Southern California Chaparral ecosystem. The four specific goals of these studies were:

1. determine if significant changes to chaparral vegetation types have occurred over the prolonged fire-free period on NBC inland training facilities that would limit applicability of findings from the greater Southern California Chaparral biome,
2. identify recent fires and associated environmental conditions occurring in vegetation types consistent with CMM and CM,
3. assess post-fire recovery for primary vegetation types in these systems as a function of fire burn severity, and antecedent and post-fire environmental conditions, and
4. identify conditions at regional and local scales that influence chaparral vegetation growth as a function of vegetation type and relative age.

Mission and training context

The specialized training facilities at CMM and CM are embedded within the Southern California Chaparral Ecosystem, in a landscape that provides unique training opportunities that simulate conditions in active military theaters far from the United States, but that brings with it unique challenges of extreme fire behavior, sensitivity to human land uses, vulnerability to introduced species, and unknown sensitivities to rapidly changing climate conditions. In addition to the challenge posed by a training location in an ecosystem adapted to high-intensity fire, the chaparral ecosystems at CMM and CM are also home to one endangered and several threatened wildlife and plant species (U.S. Navy 2013)—including the Quino Checker Spot Butterfly (*Euphydryas editha quino*). Reliance on these installations for critical training over the coming decades suggests that a greater understanding of the long-term impacts of changing climate, fire, and human impacts within and around the training sites will be necessary to make informed management decisions that promote sustainability of training operations and of the greater chaparral ecosystem.

Fire at NBC inland facilities

Within the Southern California Chaparral ecosystem, the primary disturbance agent is high-intensity crown fire, which occurs at 20-50 year intervals (Keeley and Keeley 1988). Over the past 25 years, almost two thirds of the greater southern California chaparral ecosystem has been affected by at least one fire (CalFire 2015). *However, at the inland training sites Camp Morena (CM) and Camp Michael Monsoor (CMM), more than 92% of land area has not experienced fire for more than 70 years* (Calfire 2015). The effects of this fire deficit in a system generally considered to be dependent on high-intensity fires, is not known. Fire exclusion resulting in "old growth" chaparral species and structure has a number of potential ramifications that may

influence management goals given the operational and training requirements of Naval Base Coronado. Crown fire in typical chaparral systems can result in flame lengths exceeding 8 meters (25 feet) under relatively mild wind conditions (Scott and Burgan 2005) with potential to reach more than 12 meters (40 feet) under Santa Ana wind conditions typical of late summer and early fall. High-intensity fires on or around NBC facilities can threaten infrastructure and human health through direct exposure to heat and smoke from fast-moving high-intensity fires. Additionally, the effects and behavior of fire in chaparral systems that have been fire free for nearly a century raise concerns about system resilience and additional risks posed to infrastructure, training and operations, system function, as well as direct fire risks to humans and wildlife.

Connections between climate, vegetation, and fire

California chaparral ecosystems are adapted to high-intensity crown fire, with species specific adaptations that allow for resprouting from surviving rootstock or heat and chemical activation of seedbeds that allow chaparral ecosystems to reestablish shortly after fire (Keeley 1987). A series of studies assessing chaparral response to severe drought and more frequent fires found that *Ceanothus* species, one of the most abundant genera in Southern California Chaparral is more sensitive to drought than other chaparral species and may be the most affected by an increase in heat-related drought stress in the coming decades (Davis et al. 2002). Most studies suggest that a fire interval on the order of 30-40 years allows for the accumulation of sufficient dead shrub “skeleton” material to generate high-intensity crown fire that retains the diversity of chaparral species and adaptive traits. Fire intervals shorter than 20-30 years have been shown to reduce species diversity by selecting resprouting species over reseeding species (Haidinger and Keeley 1993) and, if repeated, can result in a shift from high to lower-intensity surface fire—which promotes establishment of invasive grasses and other introduced species (Keeley et al. 2008). Changes to vegetation tolerance of extreme drought and increasing temperatures, fire behavior, and post-fire recovery in old-growth chaparral systems, and the appropriate management actions needed to address these potential changes are not known; however, recent studies suggest that Southern California chaparral ecosystems are sensitive to changing climate, with specific reference to increasingly severe drought conditions and temperature extremes (Davis et al. 2002, Coates et al. 2015).

Recent and projected climate

As noted above (Section 4.1.3), over the next several decades, the southwestern United States is expected to experience a trend of warming annual mean temperatures and increasing variability in seasonal precipitation (Garfin et al. 2014). Global Climate Model (GCM) projections for the southwest region forecast a 1-4 °F (0.5-2.2 °C) increase in summer and fall temperatures by the year 2050, with an increasing rate of warming nearer the end of the 21st century. The suite of available GCM projections suggest that the region along the US-Mexico Border is likely to experience the most severe temperature increases and reductions in winter precipitation in the southwest region. From 2012-2014 California experienced the most severe drought conditions in more than 1200 years (Griffin and Anchukaitis 2014). [At the time of the research] drought conditions persisted through the summer of 2016 and coincided with record high temperatures (Vose et al. 2014). This period of increasing temperature extremes also coincided with four of the five largest and most damaging fires in California history (CalFire 2015).

In addition to the challenges posed by uncertainty regarding the managed landscapes of Naval Base Coronado, projected increases in the frequency, duration, and severity of regional drought conditions, uncertainty regarding changes to the length of season and strength of Santa Ana winds (Miller and Schlegel 2006, Hughes et al. 2011), continuing encroachment of private land ownership, and an increasing exurban population in interior southern California pose additional challenges for military operations, training, management of fires, and land stewardship obligations. We do not attempt to address these specific concerns, but we note that decisions made regarding management of chaparral-dominated landscapes should be informed by these additional important components.

Vegetation and fire history results

Using the methods briefly described in Sections 3.2 and 3.3 and described in detail in Appendix F, we analyzed climate-vegetation-fire connections for NBC inland facilities and the broader Southern California chaparral ecosystem. To elucidate these connections, in order to inform NBC staff about detailed climate change-related risks to inland training facilities, we used a combination of the following procedures:

1. Vegetation mapping (LANDFIRE data; LANDFIRE 2016), corroborated with repeat photography ground-truthing;
2. Fire history analysis (CalFire 2015);
3. Vegetation age in response to fire history;
4. Analysis of associations between moisture, vegetation age, and fire, using remotely sensed data—Normalized Difference Moisture Index (NDMI; USGS 2015b) and Normalized Burn Ratio (NBR; USGS 2015b) and climate data (PRISM 2013)
5. Detailed analysis of post-fire vegetation responses mediated by climate, for four representative recent fires near CMM and CM

Over the study period from 1984-2011 the six dominant regional species assemblages (dry-mesic chaparral, mesic chaparral, oak-grass mix, developed-vegetated mix, coastal scrub, grass) expressed a consistent pattern of NDMI response, suggesting a widespread top-down (climate) control on vegetation moisture at the landscape scale. Individual species assemblages exhibited different degrees of sensitivity, expressed as negative or positive deviation from the scaled zero value (Figure 24). Deeper rooted oak grass-mix and mesic chaparral were least affected by the regional climate driver while shallow rooted open grassland, coastal scrub, and dry-mesic chaparral were most sensitive to regional climate variability. All vegetation types expressed increased moisture stress during the 2002-2009 regional drought that was alleviated by the 2010 El Niño winter rains. As a result of the high correlation between vegetation response curves, we selected the two most prevalent vegetation types on NBC training sites and over the whole of the study area for further analysis of vegetation age and fire severity effects on climate sensitivity and post-fire recovery. Dry-mesic chaparral (DMC) is the dominant vegetation at both CMM and CM followed by mesic chaparral (MC), grassland, coastal scrub, and developed vegetated mix (Figure 25).

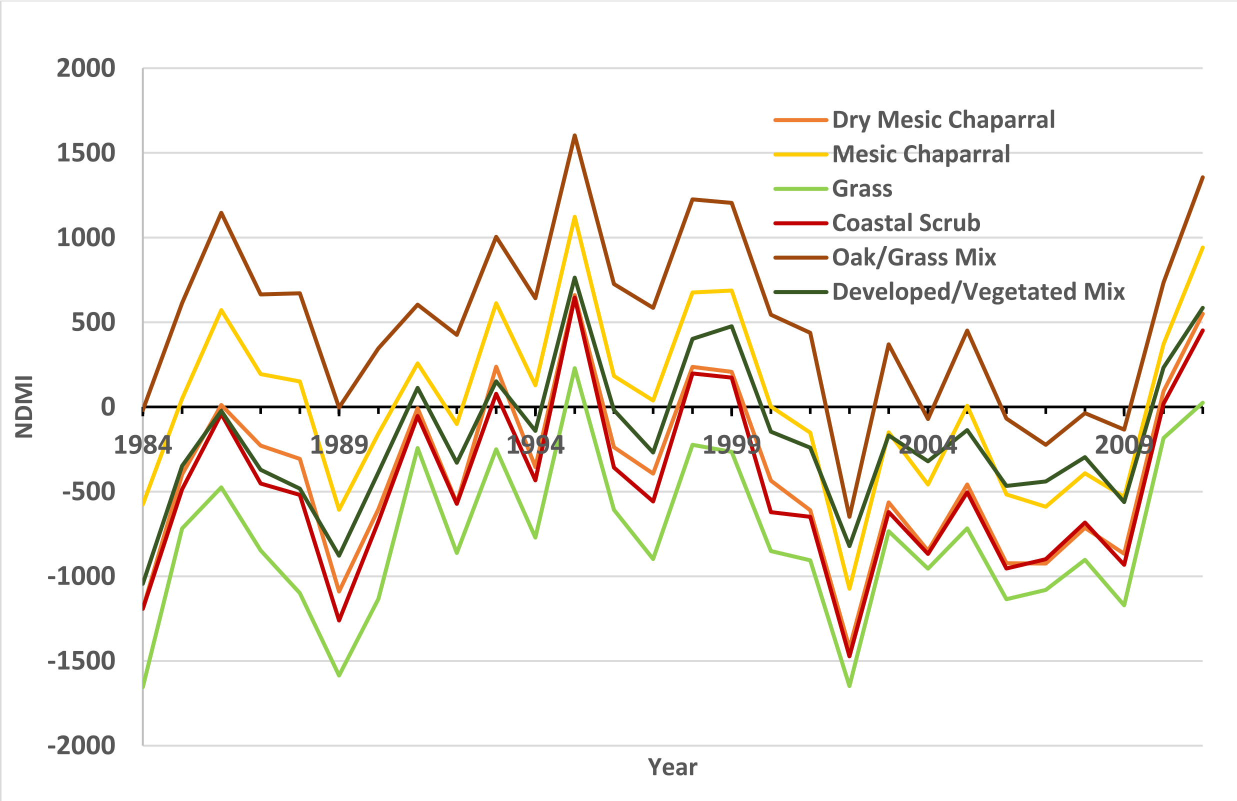


Figure 24. Vegetation response to moisture stress by dominant vegetation type.

All vegetation types express a highly correlated response to moisture stress. NDMI values below zero correlate to increasing moisture stress, values above zero indicate reduced moisture stress. The onset of the period of increased moisture stress in 2002 coincides with an increase in mean temperatures and strong drought, followed by the 2003 Cedar fire that affected more than 30% of the study area. Alleviation of moisture stress in 2010 coincides with a strong El Niño winter precipitation signal. Grass, coastal scrub, and dry-mesic chaparral were consistently the most moisture-stressed vegetation types. Oak grassland and Mesic Chaparral were consistently the least moisture stressed vegetation types.

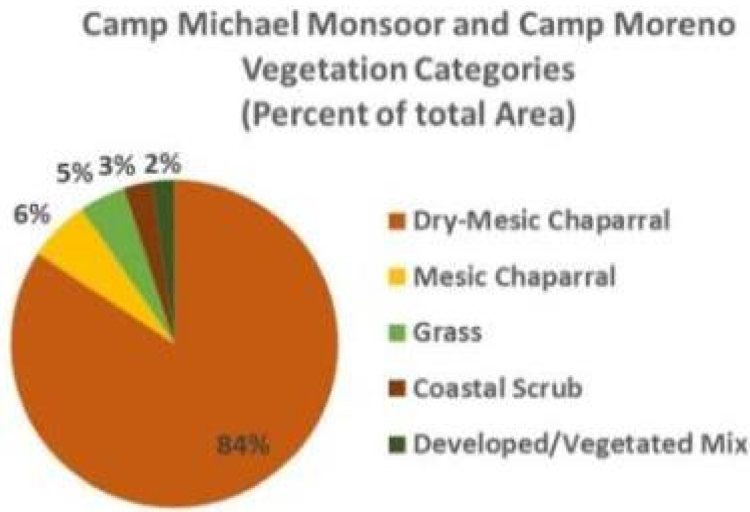


Figure 25. Vegetation composition at NBC inland training sites. Vegetation is dominated by Dry-mesic chaparral with minor components of mesic chaparral, grassland, and coastal scrub. Climate effects on dry mesic chaparral are most likely to affect operations at inland training sites.

Old growth DMC (>70 years) had significantly higher moisture stress than young DMC (<25 years) (Table 1). Moisture response curves of young and middle-aged (25-70 years) DMC assemblages were not distinguishable. A one-year temporary increase in moisture stress in the youngest DMC classes occurred in DMC affected by the Cedar Fire but not in those outside the fire perimeter. Chaparral age (time since fire) was not significantly associated with moisture stress in MC (Table 11), although the high-severity Cedar fire resulted in a nine-year increase in moisture sensitivity in the youngest MC vegetation class. Generally wetter conditions and deeper soils in this vegetation type may account for the reduced moisture sensitivity. MC did not recover from the 2003 Cedar fire as quickly as the dry-mesic species assemblage, remaining highly drought sensitive for six years following fire. MC assemblages appeared to be more sensitive to high-severity fire than DMC assemblages and less sensitive to time since fire than their dry-mesic counterparts.

Table 11 . Pairwise t-test of NDMI difference between chaparral vegetation classes older than or less than 70 years. Vegetation is partitioned into five dominant types (developed shrublands excluded). Median NDVI is a proxy for moisture response. Coefficient of variation is a measure of variability within vegetation type.

Vegetation age comparison	Median NDMI (*p*-value)	Coefficient of Variation (*p*-value)
Dry-Mesic Chaparral	0.0003*	0.9179
Mesic Chaparral	0.0956	0.3293
Grassland	0.3647	0.2134
Coastal Scrub	0.0028*	0.8906
Oak Grassland	0.8792	0.8284

Low-severity fires burning early in the fire season had little lasting effect on mesic or dry-mesic chaparral. Following both the Bobcat and Horse low-severity fires, all chaparral types returned to NDMI spectral signatures indistinguishable from control unburned vegetation within 1-2 years. Both chaparral types appear to be highly resilient to these smaller, lower severity fires that occurred under mild climate conditions, early in the fire season.

Dry-mesic chaparral expressed a similar fast vegetation recovery following the larger, higher severity Cedar and Harris fires, returning to an NDMI spectral signature similar to that of unburned DMC within a year, even in these large fires that occurred during the peak of the chaparral fire season and under more extreme drought conditions (Figure 26). In contrast, MC stands expressed a significant negative response to high-severity fire that persisted beyond the three-year period of fire-severity testing. Burned MC did not recover to the NDMI spectral signature of PRE-landsat or old growth unburned chaparral for either age class; suggesting significantly slower post-fire vegetation recover and greater vulnerability to system change following high-severity fire.

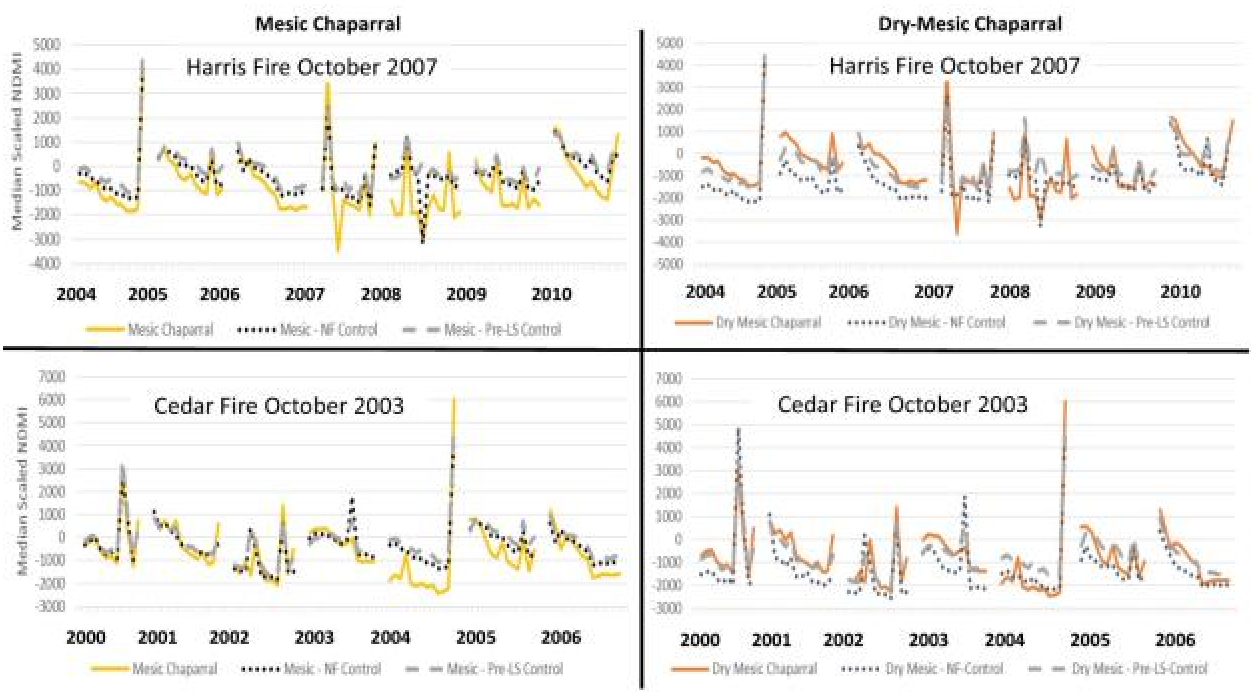


Figure 26. Chaparral response to large high-severity fires compared to unburned controls. Mesic chaparral expressed a delayed recovery following fires greater than 25% high severity. In both the Harris and Cedar fires, post-fire MC did not return to unburned vegetation response within the three-year window following fire. In contrast, DMC expressed similar vegetation response to unburned vegetation within a year following both fires.

Post-fire winter precipitation was inversely correlated with return time (months) to pre-fire vegetation moisture index. The highest severity fire in the fall of 2003 (Cedar Fire) was followed by above average total rain in the winter of 2003-2004, which may have offset some of the negative effects of high fire severity on all vegetation types affected. In the study period we did not have an example of a high-severity fire followed by persistent drought, a condition that

would be expected to slow recovery times and potentially facilitate conversion from chaparral to grassland or other more drought-adapted vegetation type.

The only environmental variable significantly associated with NDMI and NBR at the annual curing season (April to October) time step was mean curing season temperature. As temperature increased, water stress increased and NDMI (and NBR) values decreased. Mean curing season temperature explained 18-27% of the variance in NDMI for vegetation aged 25-70 years and 11-19% of the variance in NDMI for vegetation with no record of fire (100 or more years with no recorded fire). The second most important predictor of vegetation moisture stress varied by vegetation type and age; however the two most frequent secondary factors included days without rain (p-values 0.09-0.16), and pre-curing season Santa Ana Wind index (p-values 0.18-0.23), both of which were also inversely correlated with NDMI and positively correlated with water stress.

Summary of results

- While all vegetation types had a strong negative response to increasing mean temperature, the dry-mesic chaparral (DMC) type most common on CMM and CM was the most sensitive to temperature and drought extremes after ~70 years of age (i.e., “old growth”).
- *Fire burning too frequently in chaparral ecosystems surrounding DOD lands is the most immediate threat to the Southern California chaparral ecosystem*. High-frequency (at intervals less than 30 years) low-intensity fires in chaparral has been shown to promote invasion by exotic species; *thus, thinning or controlled burning at frequent intervals may promote establishment of undesirable exotic species, shifting the landscape toward more open grassland characteristics that reinforce frequent fire occurrence.*
- Continued ex-urban encroachment and greater recreational use continue to increase the number of human-caused fires in this system.
- All age classes of chaparral in this study proved to be highly resilient to fire.
- Post-fire winter precipitation appears to play a role in recovery time, and periodic moisture recharge may be necessary for maintaining vegetation in this ecosystem.
    - El Niño winters, which are usually wetter than average, would speed up post-fire recovery and help in maintaining vegetation.
    - There is much uncertainty regarding projections of future El Niñostatus. In other words, climatologists are not confident about whether future El Niños will occur more frequently and whether the regional response will continue to include higher than average winter precipitation.
    - Disruption of moisture recharge cycles, or prolonged severe drought, in the future may upset this balance.

Implications for adaptive practices and mission success

- Risk to infrastructure at CMM and CM is likely to increase as conditions become more fire prone.
- *The current policy of suppressing all fire near inland training facilities is unlikely to be sustainable over the coming decades*.
- Projected increasing prevalence and duration of drought conditions is likely to continue to degrade old-growth chaparral ecosystems and increase the potential for invasion by non-native grasses.

- Allowing old growth chaparral to burn under moderate weather conditions (e.g., the fall prior to an El Niño event), is likely to result in reduced recovery time following fire and increased drought tolerance and adaptation to current and future climate conditions for at least the next several decades.
- *One strategy to reduce the negative impacts from large high-severity fires on infrastructure and ecosystem values would be the use of a managed fire approach with planned burning that could facilitate a stepwise process of climate adaptation for inland sites, while mitigating impacts on training and landscape management obligations. Limited controlled burning near sensitive infrastructure may be warranted to reduce the risk of extreme fire behaviour and to promote vegetation adaptation to projected increasing temperatures and frequent drought conditions*.
- Where there are risk trade-offs and climate uncertainty (e.g., future winter precipitation and frequency of El Niño events), as shown in this study, it will be important for land managers and operations personnel (a) to be cognizant of potential threats to managed lands and (b) to monitor and adjust daily operations and long-term management goals to promote stability and resiliency of desired landscape attributes while working to remediate undesired conditions.
- Treatments must be weighed against the potential ecological values of old-growth chaparral that comprises a small proportion of the greater Southern California Chaparral ecosystem.
- *Development of MOUs and other cross-jurisdictional agreements with surrounding state and federal institutions better positioned than CMM and CM—where little or no wildland fire management expertise and infrastructure exists—to manage landscape-level fire processes, will allow DoD to promote long term stable and resilient landscapes that can support the training and operations missions of these unique facilities*.

4.1.9. Discussion

Through multiple interactions with Naval Base Coronado, our team tested multiple approaches to climate change risk assessment, climate services, and decision support for adaptation to climate change. We demonstrated that a combination of (a) participatory risk assessment, in a workshop setting, supplemented by (b) formal semi-quantitative risk assessment, (c) sustained and co-developed research on more narrowly defined risks, along with (d) ongoing follow-up interactions has strong potential as an integrated process for risk assessment and adaptation planning. We learned that grounding the discussion in a framework of linkages between imminent climate-related problems and chronic long-term climate change challenges is a critical element for a successful end-to-end process for embedding climate change thinking in DoD planning and activities. This imminent-chronic framing formed the basis for workshop discussions, formal risk assessment, and Tier 2 narrowly-scoped research interactions.

A key to successful formal risk assessment method is linking the assessment to existing military guidance; in the NBC case, we were fortunate to link climate change risk to existing emergency management and risk management protocols in U.S. Navy Installation Emergency Management Program Manual (CNI 3440.17). We believe that the formal risk assessment method is transparent and allows for easy explanation of cause-and-effect linkages between climate and risk. I also allows for analysis of potential cascades of impacts across functional areas, that are

often mediated by important non-climate factors, such as coordination with beyond the fence line entities, integrity of third-party infrastructure (e.g., water supply, energy generation and distribution, and transportation structures). While the risk assessment process can be time consuming, (a) it allows for a high-level installation-wide assessment, (b) assessment results can identify functions and activities that will require additional or more intensive coordination, given projected climate changes, and (c) the process can be easily conveyed, through a train-the-trainer process, in order to build assessment capacity and capacity to incorporate climate time-scale (i.e., years to decades) factors to inform decisions.

The focused Tier 2 assessment of climate-fire risks to NBC's inland training facilities revealed important trade-offs associated with fire management practices. This site-specific research and interactions with staff showed that the Southern California chaparral ecosystem in which NBC's Camp Michael Monsoor and Camp Morena are located is resilient to fire, but infrequent high-intensity fires lead to one outcome—the maintenance of the chaparral ecosystem—whereas more frequent low-intensity fires is conducive to invasion of grass species and enhanced spread of fire. NBC's practice of suppressing high-intensity fire may lead to greater risk of fire, and decreased capacity to manage for some threatened and endangered species. Our interactions with NBC staff at Camp Michael Monsoor and Camp Morena also showed a lack of installation-based expertise in fire ecology and fire risk assessment, which suggests opportunities improve fire management and landscape resilience through MOUs and partnerships with beyond the fence line federal and state agencies.

For our risk assessment method to be thoroughly useful to installation-based decision makers, ongoing interaction and support is needed. We were able to adequately provide such support through our fire risk collaboration. Nearby research organizations, such as Scripps Institution of Oceanography, were able to provide insights and some ongoing support for analysis of sea level rise-storm surge and coastal erosion risks. However, to support an installation-wide climate change risk assessment we recommend improved coordination between installation personnel, research and monitoring collaborators, contractors, and beyond the fence line land and resource managers; lack of such coordination could lead to so-called maladaptive approaches—where actions taken in with respect to one mission-critical function, in isolation from other mission-critical functions, can lead to a decrease in the ability to maintain mission readiness in the face of climate change. From our follow-up conversations, it seems that NBC is addressing some of the aforementioned concerns about coordination; however, personnel indicated that further coordination, addition of expertise, climate service assessment support, and improved communication of priorities to higher ranking decision makers would aid in linking risk priorities to adaptation action and making adaptation successful.

4.2. Case study results: Barry M. Goldwater Ranges

The Barry M. Goldwater Ranges (East/U.S. Air Force; West/U.S. Marines) constituted the second installation-based case study undertaken in this project. The ranges were selected for study, because (a) they represented different branches of the military, (b) they operated in the most extreme inland climate in our region, (c) their willingness to participate in the project, and (d) their proximity to the University of Arizona. At the outset of the project, we planned to work with each of the ranges individually; however, during the course of interactions with personnel

all parties agreed that convening a single risk assessment workshop would be preferable to separate workshops. We built on the approach used at Naval Base Coronado. One key difference was that we needed to coordinate with two branches of the military. Another key difference was that the U.S. Air Force and U.S. Marines could not procure operational emergency planning documents equivalent to the Navy Installation Emergency Management Program Manual (CNI 3440.17), Standard 4; our liaisons and the personnel with whom we interacted were unaware of a similar manual for their branches.

We began the study by conducting scoping exercises, including a review of research and literature related to the installations, an investigation into recent weather- and climate-related extreme events that caused impacts to the installations. We convened a series of preparatory visits to the installations, between April 2014 and January 2015, in which we conferred with personnel about some of their key climate- and weather-related concerns, and to garner background information about the missions of these installations. For our interactions with the Barry M. Goldwater Ranges (BMGR), we added Dr. Jim Malusa to our team. Dr. Malusa has a long history of collaborative research with BMGR, on the vegetation of DoD lands. His extensive contacts with BMGR personnel, his ongoing research, his knowledge of DoD protocols and procedures, and the trust between Dr. Malusa and BMGR personnel greatly helped our process and investigations.

4.2.1. Background

The Barry M. Goldwater Range (BMGR), established in 1941, is located in southwestern Arizona (Figure 27). It is the nation's second largest Air Force tactical aviation range. The combined east and west ranges encompass 1,733,921 acres (2,709 square miles; ~688,000 hectares), management of which is assigned to the U.S. Department of the Air Force (USAF) and U.S. Department of the Navy (USN-Marine Corps). The Air Force is the primary user of and managing agency for the eastern portion of the range, referred to as BMGR East, and the Marine Corps is the primary user of and managing agency for the western portion of the range, referred to as BMGR West. BMGR East is coordinated with USAF management at Luke Air Force Base, west of Phoenix, Arizona; BMGR West is coordinated with USN-Marine Corps management at Air Station Yuma. Because the primary military use of the BMGR is as a remote air combat training facility, with some ground combat in BMGR-West, there is relatively little infrastructure within BMGR. Primary built infrastructure includes some installation offices (BMGR-East), historic auxiliary airfields, air traffic control, heliport, target areas, a large network of access roads (including associated drainage), and a combat village facility.

The primary missions of the BMGR are to train military aircrews to fly air combat missions. However, a truncated list of military uses of the BMGR includes (USAF & USN 2013):

- Armament and high-hazard testing
- Training for aerial gunnery, rocketry, electronic warfare, and tactical maneuvering and air support
- Equipment and tactics development and testing, including an instrumented air combat tactics system for air-to-air engagements
- Helicopter landing

- Explosive ordnance disposal training and clearance areas
- Sensor training, that makes use of lasers and electronic emitters and sensors to provide a realistic urban combat training environment, and to simulate both air-to-ground and ground-to-air weapons use
- Sand and gravel excavation for road and target repair

BMGR West, in addition to aviation ranges and air combat training, includes air-to-ground training facilities, and also has facilities for ground combat, rifle, small arms and other training.

The region in which the BMGR is located is predominantly rural and undeveloped. The BMGR lands are bordered by lands under the jurisdictions of the BLM, Bureau of Reclamation, USFWS, the Tohono O'odham Nation, and private or State Trust lands (Figure 28); in addition 38 miles (or 11% of the perimeter of BMGR, all within BMGR-West) forms part of the international boundary between the United States and Mexico (Figure 28). Along the northern border of BMGR, private and State Trust lands are primarily devoted to agricultural crop production, which is also the predominant land use to the immediate west of the BMGR (Figure 28). Nearby, to the northeast is the city of Gila Bend, Arizona, and to the west is the city of Yuma, Arizona. Interstate Highway 8 runs near BMGR's northern border, and Arizona State Route 85 runs north-south across part of BMGR-East.

A feature of BMGR's location is that "[m]ost of the adjoining federal, tribal, and Mexican lands are in undeveloped conditions and are dedicated to long-term conservation purposes or are used for a combination of conservation and multiple public use purposes" (USAF & USN 2013). Consequently, BMGR is situated as a component of the largest relatively unfragmented and undisturbed portion of the Sonoran Desert—the most biologically diverse of the North American deserts—within the United States. Moreover, the BMGR's training footprint, restricted training airspace, extends into adjacent federal lands. The Sikes Act requires that BMGR lands be managed for wildlife, habitat protection and enhancement, protection of wildlife or plants, enforcement of applicable natural resources laws and regulations, and other natural resource values and concerns. In addition the Military Lands Withdrawal Act of 1999 requires the BMGR to meet trust responsibilities of the U.S. with respect to Native American tribes and associated lands and treaty rights, including access to sacred sites (as feasible with military purposes), and consultation of with affected Native American tribes with respect to changes in management actions. A key facet of land management responsibilities for BMGR includes taking necessary actions to prevent, suppress, and manage brush and range fires within the BMGR and those occurring outside of the BMGR, if they result from military activities.

In 1999, the Military Lands Withdrawal Act reauthorized military use of the range and assigned jurisdiction and land management authority to the Secretaries of the Air Force and Navy for their respective portions of the range. The 56th Range Management Office (56 RMO) administers the land and airspace of approximately 1 million acres of the BMGR-East. The 56 RMO staff and contractors include natural resource management personnel, responsible for tasks such as inventory and monitoring of vegetation and wildlife species, documentation of preservation of threatened and endangered species, and identification of hazards pertaining to mission readiness, such as erosion and other threats to roadways used for access to targets, explosive ordnance disposal, and other mission-related facilities. Cultural resources personnel—archeologists, are responsible for identifying, documenting and protecting heritage historic and prehistoric sites and

artifacts, historic buildings, in accordance with federal policies. The 56 RMO staff includes liaisons to neighboring Native American tribes, other federal landholders (e.g., BLM), and state and local entities.

In addition, BMGR-E offices house active duty personnel responsible for operations related to aircraft guidance, target maintenance, electronics and technology, explosive ordnance disposal, infrastructure, and other tasks. BMGR West staff also have responsibilities for natural and cultural resource management, in addition to road monitoring. The Arizona Game & Fish Department (AGFD) has primary jurisdiction over wildlife management within the BMGR, except where pre-empted by federal law. Some of the responsibilities assigned to the AGFD include: habitat evaluation, protection, and enhancement projects; wildlife population surveys; shared management of federally listed endangered species; enforcing hunting regulations. The BMGR also affords some recreational public uses of its lands, as long as those uses are in accordance with military use and natural resource management regulations and priorities.

A notable feature of BMGR's location and land management is its situation with respect to the U.S.-Mexico Border. As mentioned above, the BMGR shares part of the international border; but given the proximity of the entire BMGR land holding to the border, the BMGR is also subject to cross-border traffic, such as undocumented immigrants (UDI), drug smugglers, and others. Consequently, BMGR personnel collaborate with the U.S. Customs and Border Protection component of the Department of Homeland Security. Cross border traffic, and activities to apprehend illegal crossers, adversely affects soils, hydrology, ecosystems, wildlife, natural resources, and roadways.

Sensitivities and other Factors Mediating Exposure to Climate Change

From our literature review, focus group sessions with BMGR personnel, and webinar with adjacent land owners, we learned of some key intervening factors related to potential effects of climate change, as well as some concerns with weather and climate-related hazards.

Soil and road conditions are a key concern of all BMGR personnel; ground disturbance is a particularly important intervening factor at BMGR-West, where it was mentioned prominently during our pre-workshop focus group briefing. Routine training activities are designed to minimize impacts to soil surfaces. Construction of a section of barrier fence along the U.S.-Mexico border required substantial road grading to provide access to trucks hauling heavy equipment into the area. Repeated road grading has altered the land surface such that berms have been created along the road sides, which then impedes surface drainage and accelerates erosion. The Border Patrol also effectively grades desert surfaces, through its use of surface smoothing surveillance techniques to record new foot or vehicle traffic (so called "dragging" the surface) (USAF & USN 2013). As mentioned above, off-road foot and vehicle traffic of UDIs, and of Border Patrol law enforcement personnel in pursuit of UDI traffic, has created an expanded network of drainage channels that has altered hydrology, overland flow, ecosystem function and habitat for threatened and endangered species, and accelerated erosion—through channel incision. The effect of this cascade of impacts, which mediates the effects of episodes of drought, extreme rain and wind, is that it undermines roads and directly impedes USMC training activities, and indirectly contributes dust and particles that diminish visibility and air quality. The latter, in addition to natural dust storms, can affect air and ground training missions.

Invasive vegetation species are an important intervening factor that mediates exposure to weather and climate at BMGR. BMGR staff mentioned *Schismus* species, buffelgrass (Pennisetum ciliare), fountain grass (Pennisetum setaceum), and Sahara mustard (*Brassica tournefortii*); these species contribute to changes in ecosystem structure by competing with native species and through massive proliferation which enhances the spread of wildfires. The 2012 update to the BMGR Integrated Natural Resources Management Plan notes that the primary vectors for these invasive species include people, automobiles, livestock grazing on adjacent lands, and so-called trespass livestock (e.g., burros) that cross onto BMGR lands (USAF & USN 2013). Much of the expansion of these species is occurring on highway right-of-way along Arizona State Route 85, and through ground disturbance associated with UDIs and Border Patrol.

Threatened and endangered species are important to the management of BMGR lands and the continuity of military training mission readiness. The presence of Sonoran pronghorn (*Antilocapra Americana sonoriensis*) and lesser long-nosed bat (*Leptonycteris curasoae*), which are federally listed species, is well documented. Personnel mentioned other species of concern, including the desert tortoise (*Gopherus agassizii*), acuña cactus (*Echinomastus spp*.), and flat-tail lizard (*Phrynosoma mcallii*); the latter is of special concern for BMGR-West. Acuña cactus is the only plant species showing an increased vulnerability to climate change, in a 2012 study (Bagne and Finch 2012). BMGR personnel participate in numerous meetings with a variety of surrounding landowners and wildlife specialty agencies (e.g., the Phoenix Zoo) as part of a Sonoran Pronghorn Recovery Team. In support of the AGFD and U.S. Fish and Wildlife Service efforts, BMGR personnel contribute to pronghorn monitoring; personnel noted the deployment of 22 motion-sensing cameras, along with other electronic and photographic monitoring.

Wildfire was mentioned as an important climate-related impact in the BMGR-East lands. We consider it a mediating factor, because of the enhanced spread of wildfire due to invasive species. Personnel prominently mentioned a 2005 fire, on the order of 130,000 acres, that “shut everything down.” Key concerns include ignitions from UDIs, and further sensitivity to fire, as a result of the spread of invasive species. Personnel mentioned partnership activities with the U.S. Forest Service, to develop a fire management plan for BMGR.

Two positive intervening factors have to do with the excellent *cooperation and collaboration* with federal and state agencies, mentioned by BMGR personnel, during our preparatory visits. The Sonoran Pronghorn Recovery Team is one example. The BMGR Executive Council (BEC), which consists of agency representatives of managers for adjacent land management agencies. The BEC is an ad hoc committee, and they work together to exchange information and advice on solutions for natural and cultural resource management issues (USAF & USN 2013). The second intervening factor is ecosystem-based management philosophy of BMGR, which incorporates (a) adaptive management, and (b) cooperation of diverse academic disciplines to allow for effective ongoing assessment, research, and monitoring (USAF & USN 2013).

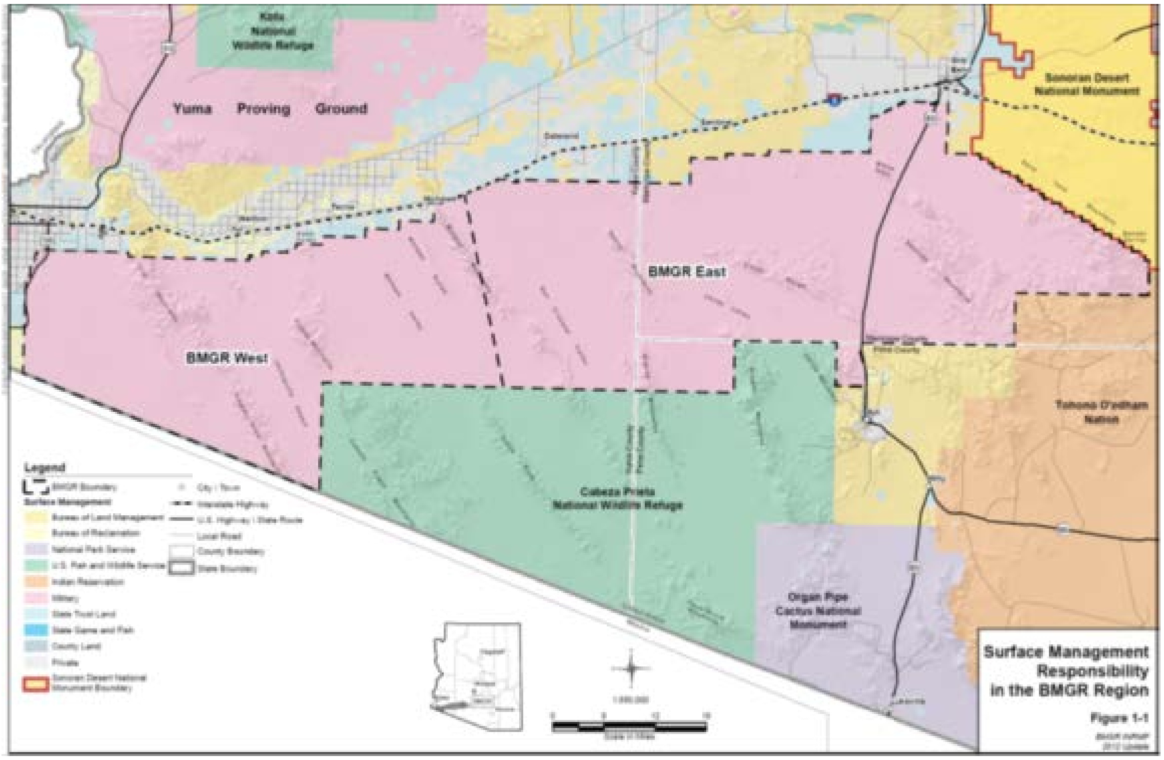


Figure 27. Barry M. Goldwater Ranges (BMGR) and adjacent land ownership. Source: U.S. Department of the Air Force and U.S. Department of the Navy, 2013.

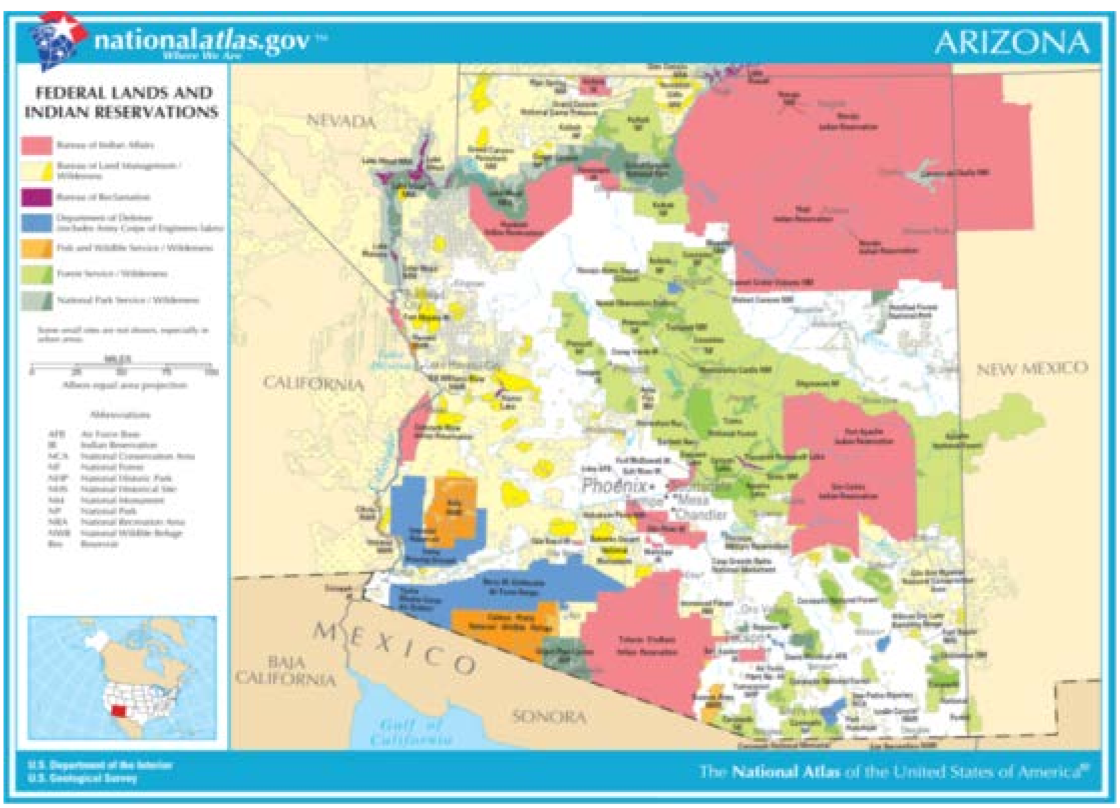


Figure 28. Federal lands in Arizona. (Source: USGS; nationalatlas.gov).

*Workshop process.*We used a similar workshop process to the one we used at Naval Base Coronado. Our process included an initial session focused on historical weather-related events, and were asked to work in small groups to record the impacts and consequences for BMGR. We followed this with a session aimed at determining BMGR's and neighboring agencies' key objectives and success criteria. We then introduced two future climate scenarios (described below), custom-designed for BMGR, based on our expert assessment derived from results of authoritative reports, such as the National Climate Assessment; participants then generated an inventory of risks and opportunities associated with the future climate scenarios. Where possible, participants were asked to identify key sensitivities and critical thresholds. For each seasonal scenario, participants voted on the risks they deemed a priority, based on the following criteria:

- *Critical thresholds may be breached*
- *Systems highly sensitive to changes*
- *Decisions with long-term consequences*
- *Where "failure is not an option"*

Recognizing that risks are trans-boundary and likely to cut across areas of performance, different organizations and community divisions, participants explore risk interconnections. They reviewed each other group's inventory of climate change risks and opportunities, and highlighted the consequential risks to their own group. Our fourth session brought together all participants to develop a consensus on the issues participants felt were most critical to BMGR. Finally, taking the two most critical risks identified, groups discussed how these risks are currently managed and how future experiences with these risks may be managed. To focus the discussion, for each risk we went through the following series of questions:

- *Roles and responsibilities – who manages this risk?*
- *Existing guidance – what current plans are currently in place for this risk?*
- *Existing controls – what is the process for dealing with this risk?*
- *Needs – what informational/human resources/financial resources/monitoring is needed*
- *Barriers – what is getting in the way, or may get in the way of responding?*
- *Opportunities – what are the enabling factors promoting a response, and are there benefits to acting now?*

Following the workshop, we reported our findings back to the installations.

4.2.2. Objectives and success criteria

Workshop participants divided into three groups, according to their major mission responsibilities: built infrastructure, natural resources, and operations. The success criteria provided a tangible link to cause-and-effect chains of events related to observed and potential future exposure to climate and weather.

Table 12. BMGR success criteria, identified by February 2015 workshop participants. In each column the criteria are listed in triplets of (a) function, (b) objectives, (c) success criteria

Operations and Training	**Infrastructure and Transportation**	**Natural and Cultural Resources**
Fighter flight operations, training, safety and adherence to schedule	Policing roads, safety, perimeter maintained	Wildlife monitoring, mission readiness, compliance with Endangered Species Act
Ground control, training target designation, safety	Incident response and traffic control for the public, safety, timely response and/or road closure	Water management, personnel comfort and basic needs, adequate supply and water quality compliance
Ordnance equipment testing, equipment and procedure success, safety	Transportation, employee and equipment timely and safe travel, roads remain open to personnel and contractors	Climate and weather monitoring, mission readiness, data quality and consistent monitoring across land ownership
Mission essential services, target and electronic equipment maintenance, clear ground access to sites		Safeguard cultural and biological resources, cultural resources protection, no new disturbance
Remote training operations, successful take off-landing-encampment, safety and access to encampment sites		

The overarching success criteria for the BMGR, based on conversations with personnel, include (a) no net loss of military training capacity and training timeliness, (b) demonstration to the public of no adverse effects to safety, livelihoods, natural resources and wildlife, and transportation, due to BMGR operations, and (c) adequate maintenance of cultural resources. Combining BMGR and neighboring agencies' key objectives and success criteria, based on workshop exercises, the following very similar criteria emerged: (a) maintaining operational and training readiness, supported by routine monitoring of environmental and climate data, (b) ensuring safety on the range and supporting infrastructure, and (c) promoting cooperation with other groups.

4.2.3. Exposure to current and future climate changes

We used a similar approach to introducing climate information and discussing exposure to climate drivers, as in our NBC workshop (see Section 4.1). At BMGR, we built upon pre-workshop discussions with personnel, regarding weather- and climate-related issues affecting operations and training, infrastructure and transportation, and natural and cultural resources management. Again, our initial workshop discussion focused on recent weather- and climate-related events, episodes, impacts and responses. To seed the conversation at BMGR, we presented information on recent climate- and weather-related surprises, from our research and pre-workshop conversations with installation personnel (Figure 29).

Figure 29. Photomosaic illustrating impacts of the January 2010 flood at MCAS Yuma. This winter flood had impacts throughout the BMGR lands.

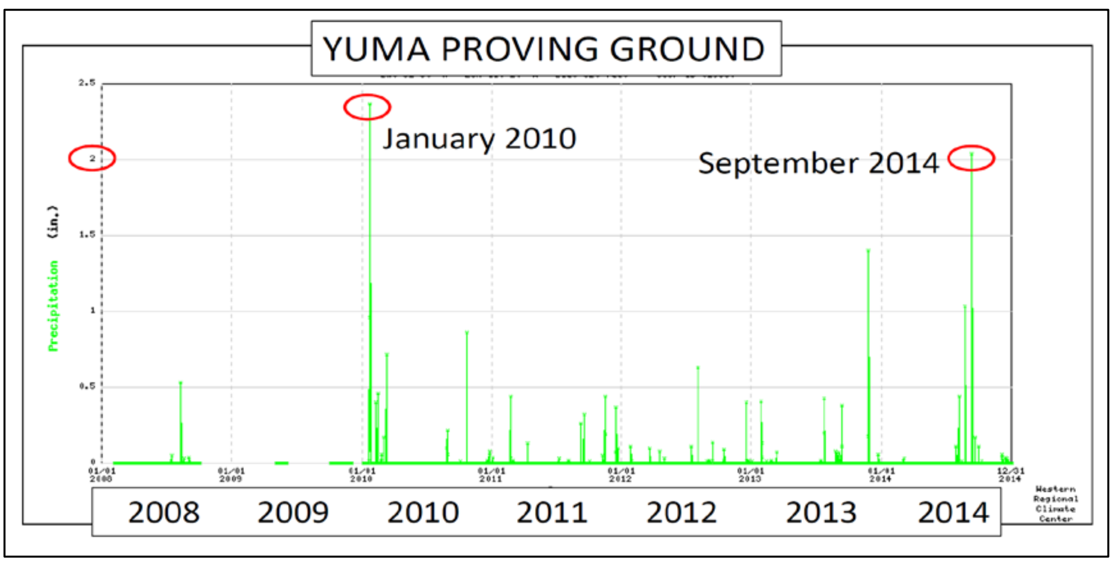


Figure 30. Daily precipitation for the Yuma Proving Ground weather station, illustrating infrequent high precipitation (> 2 in.) events that led to flooding at BMGR and associated facilities. (Data: Western Regional Climate Center).

Participants, working in small groups, then contributed examples of recent events, consequences, and responses at BMGR.

- Extreme summer rainfall events (e.g., late-August and early-September 2014 in the southern portion of BMGR east), which tend to be highly localized and lead to:
    - Wash out of a primary road (“airforce road”)
    - Roads are impassable until water recedes
    - Closure of the highway at dip crossings
    - Clean-up operation to remove debris from roads
    - Extensive repair program for roads damaged, including the creation of a new road on the range
    - Field staff modifying their work hours and activities
    - Military operations impacted (diverted aircraft, range closure)
    - Exposure of cultural resources, which required emergency consultation / mitigation
    - Affected pronghorn monitoring as field staff couldn’t access sights
    - Proliferation of plants following rain/ dry cycles (increasing future fire risk)

- Wildland fires [e.g. June 2005], leading to:
    - More than 130,000 acres burned (USAF & USN 2013)
    - Flight operations were impacted during the fire; resumed after fire suppression
    - Emergency consultation and fire management plan
    - Possible increase in the frequency of dust storms

Historic climate variations pertaining to BMGR.

The word “extreme” was designed to describe the weather and climate of the BMGR. The region encompassing BMGR receives approximate 5 inches of rainfall per year, with up to around 9 inches at higher elevations in the easternmost portion of the BMGR (Chris Black, BMGR-East, personal communication). As with most extreme desert environments, interannual precipitation variability is exceedingly high, and intraseasonal variability is also high. Most of the annual precipitation occurs as a result of winter season frontal storms, highly affected by fluctuations in the El Niño-Southern Oscillation, or as a result of summer monsoon thunderstorms. The region is characterized by some of the highest average temperatures in the contiguous U.S., with maximum summertime daily temperatures in excess of 110°F and very high rates of evapotranspiration.

Based on the 3rd National Climate Assessment (Melillo et al. 2014), and the technical input report for the Southwest region (Garfin et al. 2013), many locations in the Southwest have experienced warmer temperatures in recent decades, compared to the 1901-1960 average (Figure 31). Since the 1990s, average temperatures have been over 1.5°F (~0.8°C) higher than the 1901-1960 average for the region around BMGR. The inset graph in Figure 31 shows that the period from 2001 to 2011 was warmer than any previous decade in the Southwest.

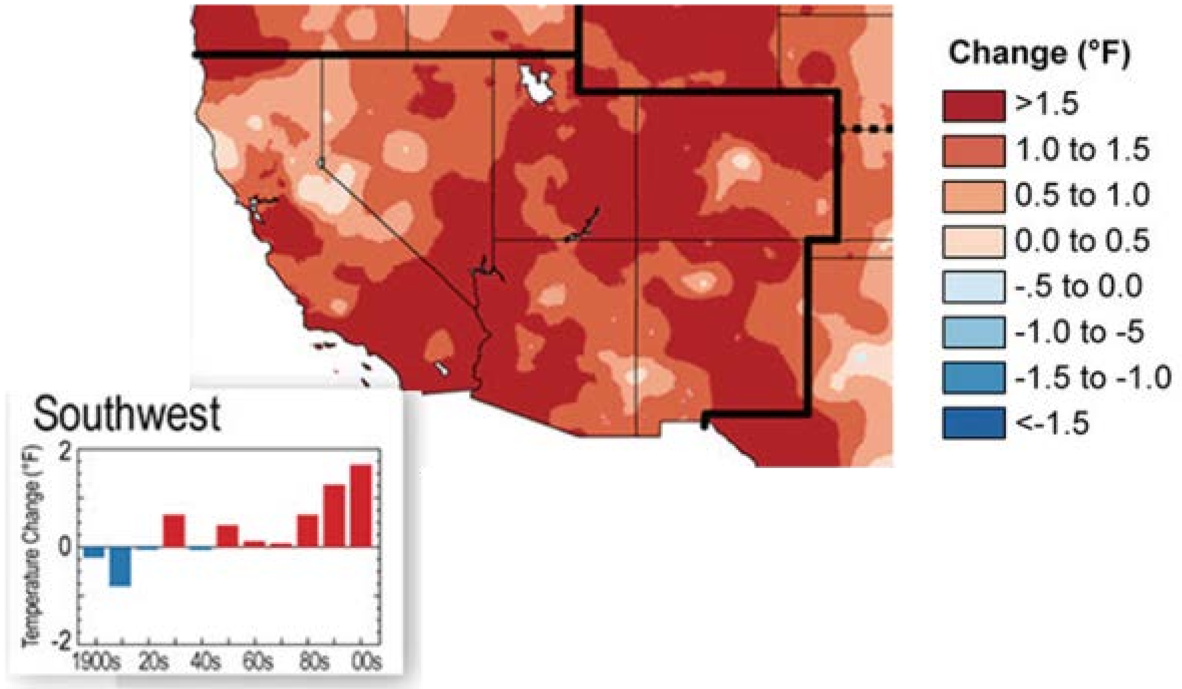


Figure 31. Map shows temperature changes over the past 20 years in °F (1991-2011) compared to the 1901-1960 average. Inset graph show the average temperature changes by decade for 1901-2011 (relative to the 1901-1960 average) for the Southwest region (Data source: NOAA NCDC / CICS-NC; in Walsh et al. 2014).

Concurrent with this warming in average temperatures, there has been a decrease in the number of cold snaps and an increase in the number of heat waves during recent decades (Hoerling et al. 2013). A key point presented to workshop participants is that relatively small shifts in mean climatic conditions, like warmer temperatures, can lead to large changes in the occurrence of extreme events, like heat waves.

There is less of a discernible trend in precipitation across the Southwest region in recent decades, as indicated in Figure 32 by the positive and negative percent changes in annual totals, compared to the 1901-1960 average; the region near BMGR shows substantial decreases in annual average precipitation, due to drought exacerbated by higher than average temperatures. The inset graph shows the strong decadal precipitation variability in the region, which is characteristic of decadal precipitation variability affecting BMGR and the southern tier of Southwest states. For regional precipitation extremes in the context of very heavy daily rain events (defined as the heaviest 1% of all daily events from 1901-2011 compared with the 1901-1960 average), there is no statistically significant trend across the region over the past century (Figure 33), although heavy precipitation has increased by 5% (Walsh et al. 2014).

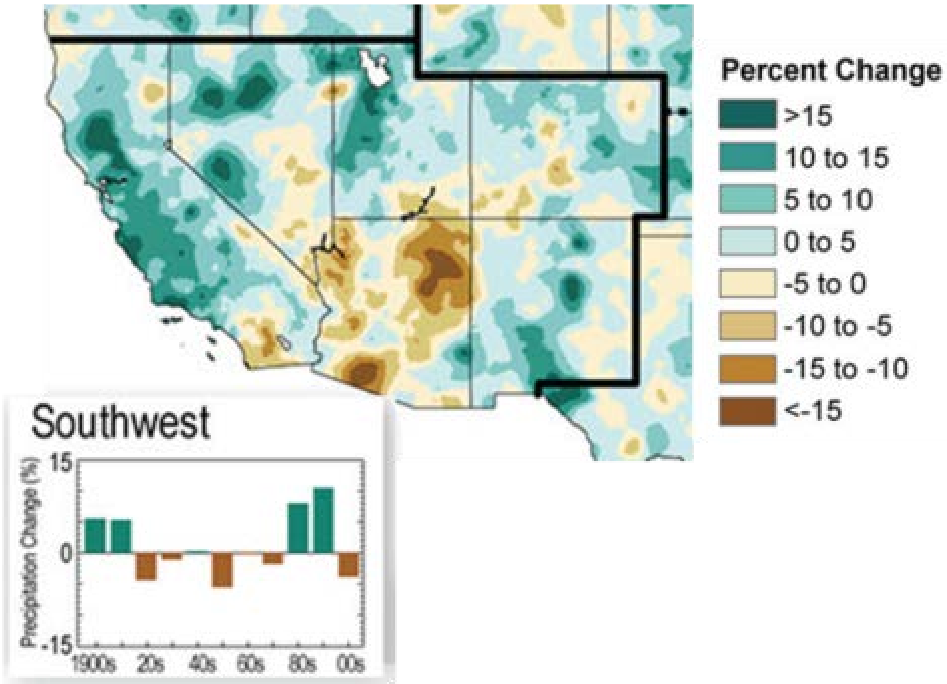


Figure 32. Map shows annual total precipitation changes (percent) for 1991-2011 compared to the 1901-1960 average, and show wetter conditions in most areas. Inset graph shows average precipitation differences by decade for 1901-2011 (relative to the 1901-1960 average) for each region (Data source: NOAA NCDC / CICS-NC; in Walsh et al. 2014).

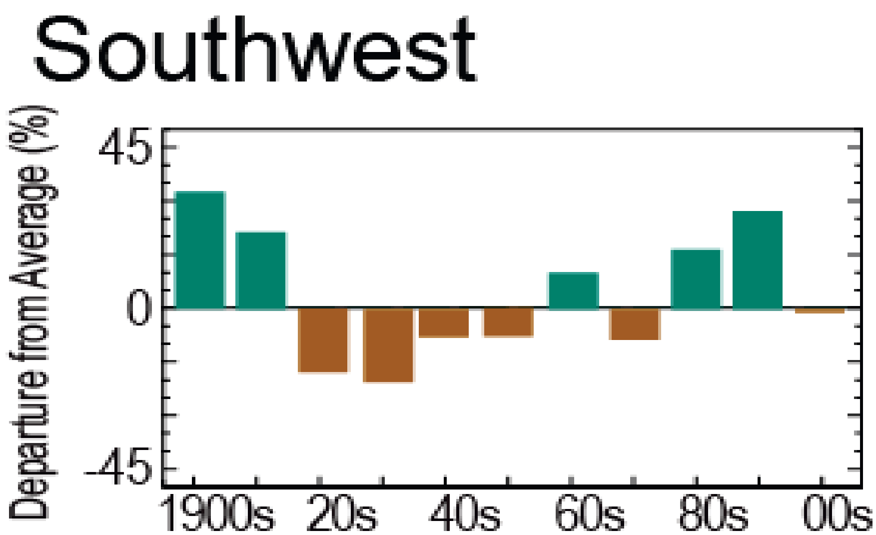


Figure 33. Changes in annual precipitation falling in very heavy events, compared to the 1901-1960 average (Data source: NOAA NCDC / CICS-NC; in Walsh et al. 2014). Heavy events are defined as the heaviest 1% of all daily events from 1901 to 2011.

We followed up with a presentation of projected regional future climate and specific scenarios tailored to BMGR's regional climate and location (below).

Projected future climate for BMGR.

Our interactions with BMGR personnel followed the release of the 3rd National Climate Assessment (Melillo et al. 2014) and the widespread availability of downscaled CMIP5 climate projections. Thus we were able to incorporate updated material in our presentations to and discussions with BMGR personnel. In general, the Southwest is expected to continue warming during the 21st century, with a longer heat season, including longer and hotter heat waves, and more intense, severe, and frequent droughts (Garfin et al. 2013). These changes will likely have profound impacts on the natural environment, water resources, energy demand and distribution, agriculture, urban areas, human health and trans-border issues. Our team developed two custom scenarios of future climate for the region encompassing BMGR, incorporating the assumptions of the RCP 8.5 emissions scenario (van Vuuren et al. 2011). In climate change research, scenarios describe plausible trajectories of different aspects of the future that are constructed to help investigate the potential consequences of man-made climate change (IPCC 2013b). We used these scenarios, described in greater detail, below, in order to consider how future climate may affect risks related to successfully meeting BMGR's missions.

The two future scenarios for the BMGR risk assessment were:

(1) Winter/Spring future climate; and
(2) Summer/Fall future climate

Scenario 1 – Winter/Spring: Warmer and drier with occasional heavy rainfall – Climate exposure

Key characteristics of Scenario 1:

- Temperatures rise substantially over the course of the century, with the greatest warming during the summer season (Figure 34, Table 13)
- Precipitation declines slightly in winter (medium confidence) and to a greater degree in spring (high confidence) (Figure 35, Table 13), but year-to-year and decade-to-decade variations still result in wet spells and droughts.
- Occasional heavy winter rainfall would most likely be conveyed by relatively predictable El Niño-Southern Oscillation atmospheric circulation, atmospheric rivers (e.g., "Pineapple Express"), or other frontal storms in the winter westerly (west-to-east) atmospheric circulation (Cayan et al. 2013).

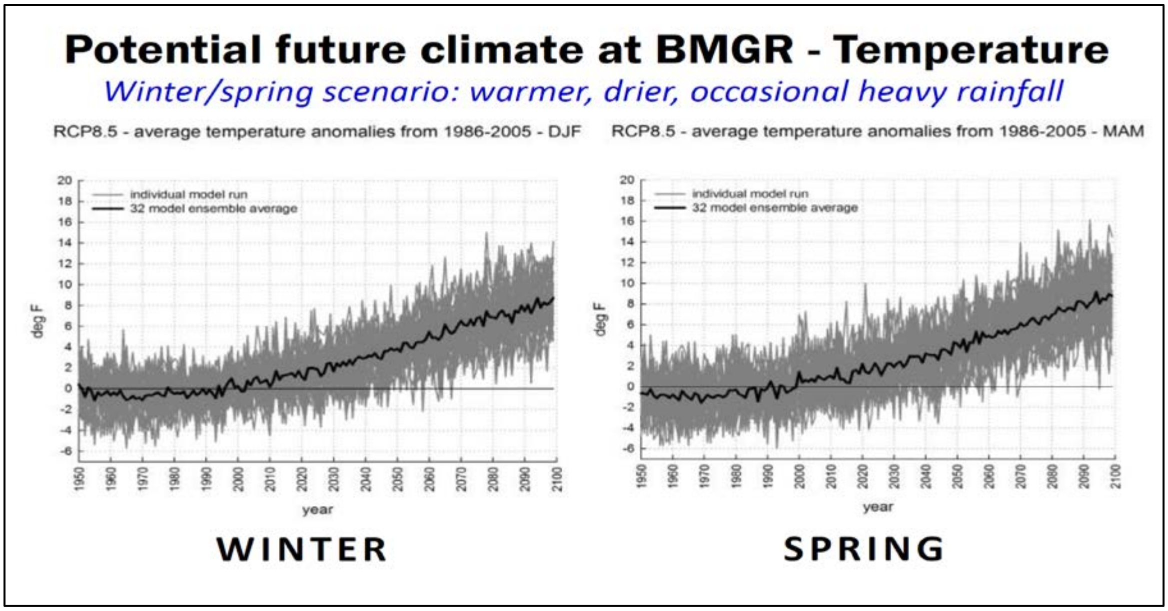


Figure 34. Downscaled projections of future winter (left) and spring temperature (right) for BMGR, based on RCP 8.5 emissions, and expressed as departure from the 1986-2005 mean, in degrees Fahrenheit. Gray lines show projections from 32 individual GCMs; black line shows the 32-model average. Data: Reclamation and others downscaled CMIP3 and CMIP5 climate and hydrology projections (http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html).

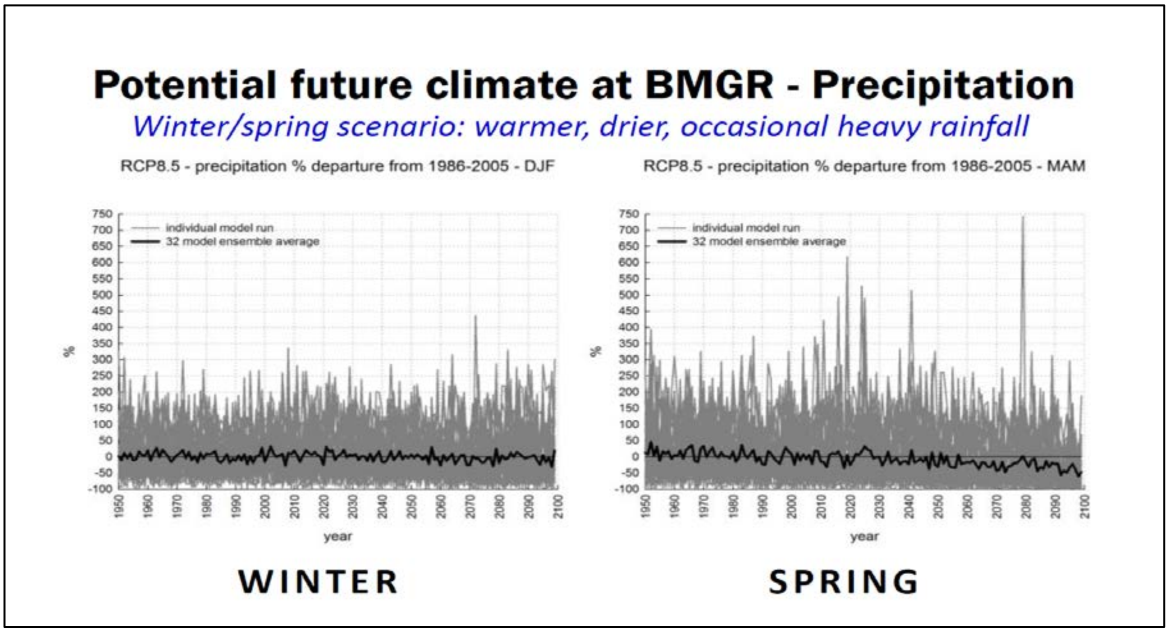


Figure 35. Downscaled projections of future winter (left) and spring precipitation (right) for BMGR, based on RCP 8.5 emissions, and expressed as a percent departure from the 1986-2005 mean. Gray lines show projections from 32 individual GCMs; black line shows the 32-model average. Data: Reclamation and others downscaled CMIP3 and CMIP5 climate and hydrology projections (http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html).

Table 13: Winter and spring temperature and precipitation projections used in BMGR Scenario 1. Values denote annual change in average from 1986-2005 and were drawn from 32 projections based on the CMIP5 high-emissions (RCP 8.5) scenario (van Vuuren et al. 2011), and downscaled, by team member Jeremy Weiss, to the region encompassing BMGR. Data: Reclamation and others downscaled CMIP3 and CMIP5 climate and hydrology projections (http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html).

Winter/spring scenario: warmer, drier, with occasional heavy rainfall

WINTER

	2011-2040	2041-2070	2071-2099
temperature*	+ 1.9°F (+ 1.1°C)	+ 4.4°F (+ 2.4°C)	+ 7.3°F (+ 4.1°C)
precipitation*	+ 4.1%	- 3.0%	- 3.4%

SPRING

	2011-2040	2041-2070	2071-2099
temperature*	+ 1.8°F (+ 1.0°C)	+ 4.4°F (+ 2.4°C)	+ 7.5°F (+ 4.2°C)
precipitation*	- 3.2%	- 16.7%	- 28.8%

*seasonal change in average from 1986-2005 for RCP8.5 32 model ensemble mean

(projection data archive at: gdo-dcp.ucllnl.org/downscaled_cmip_projections)

Mean winter and spring temperatures increase across all future projections during the course of the 21st century (Table 13). NARCCAP projections of maximum temperatures (T_{max}) greater than 100°F (SRES A2 emissions scenario; figure not shown), produced for the 3rd National Climate Assessment, show consecutive T_{max} > 100°F days increasing by 21-27 days in the 2041-2070 time period, when compared with the 1971-2000 average.

Seasonal precipitation, under assumptions of RCP 8.5 emissions, is projected to decrease slightly in winter and substantially in in spring (Figure 5). Spring is usually a dry time of year in the northwestern Sonoran Desert, where BMGR is located; however, less reliable winter and spring precipitation translates to a longer dry season, which has ramifications for wildlife and vegetation. Spring precipitation is projected to decrease by almost 29% by the end of the 21st century, compared to the 1986-2005 reference period. This regional drying trend during these seasons will be driven in part by the jet stream's shift to the north, shunting storm systems – and the precipitation they deliver – away from the Southwest (Figure 36).

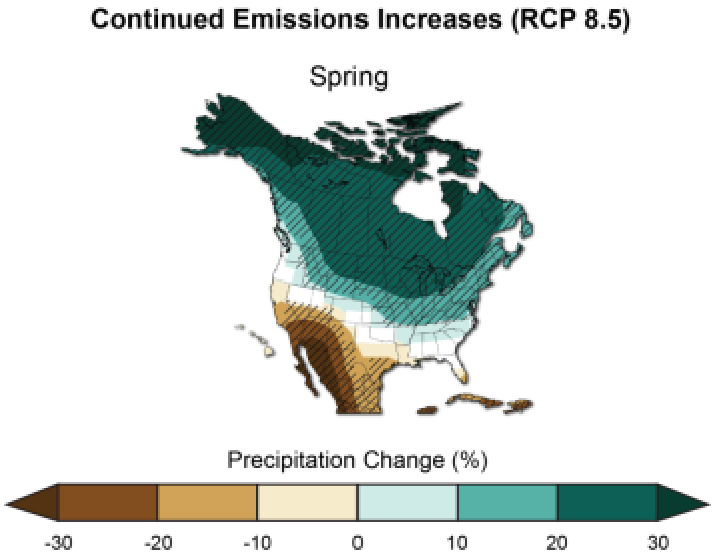


Figure 36. Projected percent change in seasonal precipitation for 2071-2099 (compared to the period 1970-1999) under the RCP 8.5 (high) emissions scenario. Green indicates precipitation increases, and brown, decreases. Hatched areas indicate that the projected changes are significant and consistent among models. White areas indicate that the changes are not projected to be larger than could be expected from natural variability. (Figure source: Walsh et al. 2014).

Though this scenario projects less total annual precipitation, a warmer atmosphere nonetheless has the capacity to hold more water vapor. This means that even while seasonal precipitation totals decrease, the rate at which precipitation falls may increase, leading to more intense rain events, as well as potentially shorter return periods of heavy precipitation. Particularly important for BMGR is the occasional advection of massive amounts of moisture into Arizona, in winter and spring, by so-called "atmospheric rivers" (Neiman et al. 2013; Hughes et al. 2014).

Scenario 2 – Summer/Fall: Warmer, with extreme uncertainty in rainfall amount, and possible increase in torrential rainfall – Climate exposure

Key characteristics of Scenario 2:

- Temperatures rise substantially over the course of the century (Figure 37, Table 14)
- Precipitation increases in summer and fall (low confidence), with very high uncertainty in summer and fall precipitation, due to a high spread among model projections (Figure 38)
- Possible increases in summer and early fall torrential rainfall as shown in Figure 39, are due primarily to increased tropical cyclone activity affecting northwestern Mexico and southwestern Arizona (low confidence)

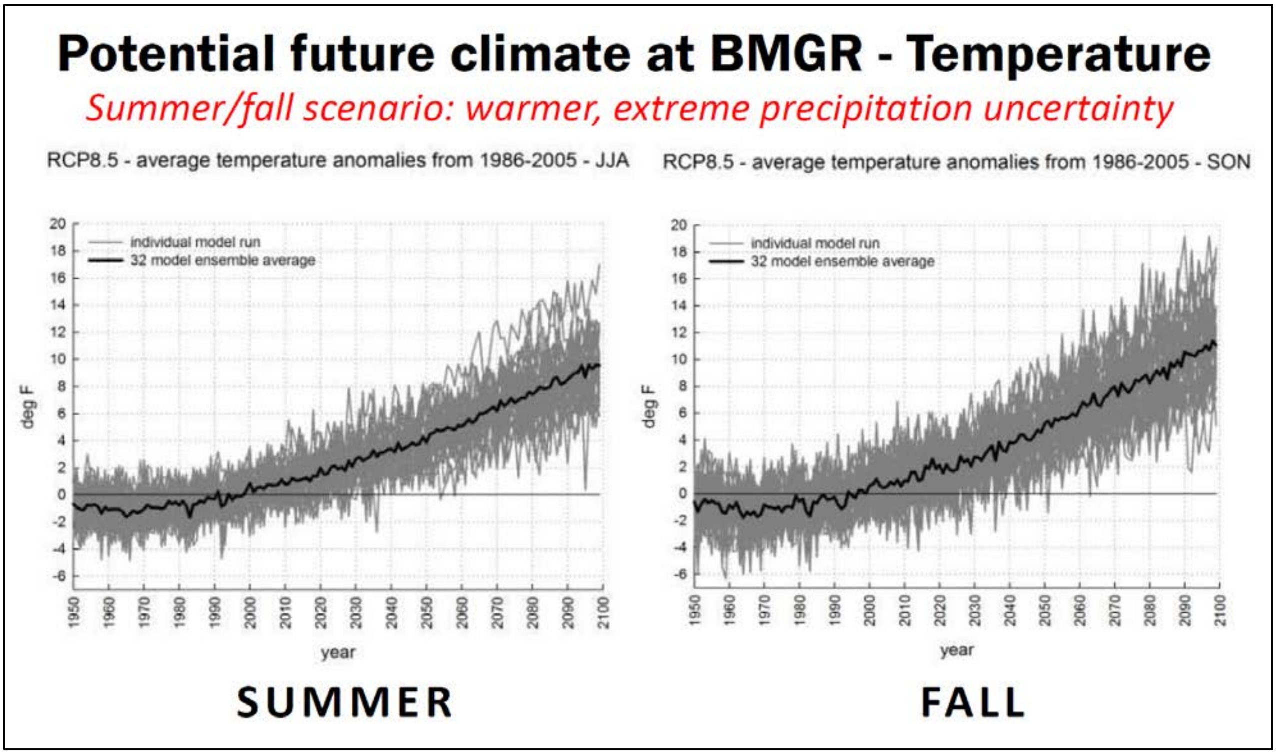


Figure 37. Downscaled projections of future summer (left) and fall temperature (right) for BMGR, based on RCP 8.5 emissions, and expressed as a departure from the 1986-2005 mean, in degrees Fahrenheit. Gray lines show projections from 32 individual GCMs; black line shows the 32-model average. Data: Reclamation and others downscaled CMIP3 and CMIP5 climate and hydrology projections (http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html).

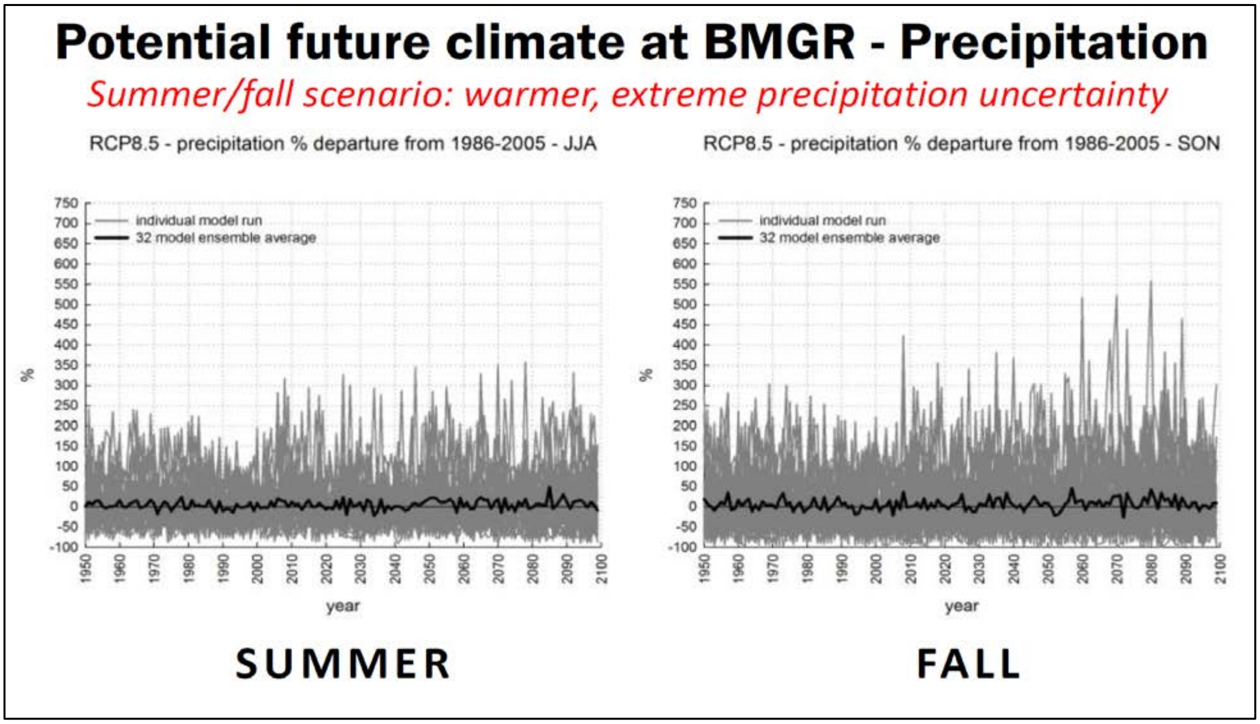


Figure 38. Downscaled projections of future summer (left) and fall precipitation (right) for BMGR, based on RCP 8.5 emissions, and expressed as a percent departure from the 1986-2005 mean. Gray lines show projections from 32 individual GCMs; black line shows the 32-model average. Data: Reclamation and others downscaled CMIP3 and CMIP5 climate and hydrology projections (http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html).

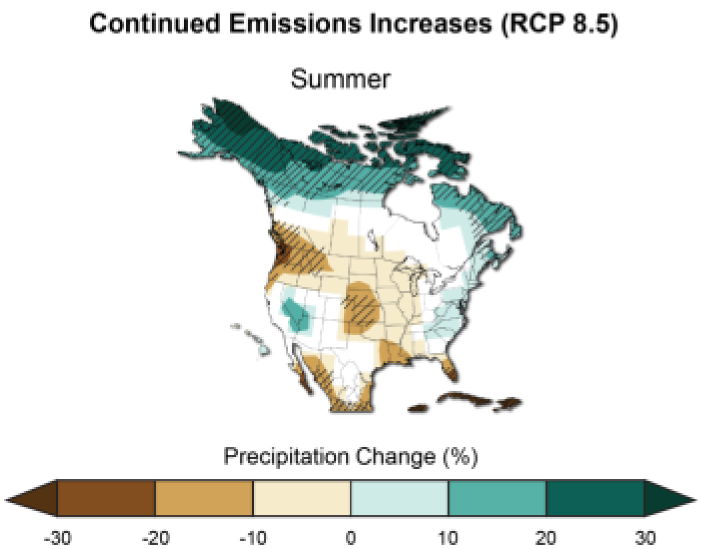


Figure 39. Projected percent change in seasonal precipitation for 2071-2099 (compared to the period 1970-1999) under the RCP 8.5 (high) emissions scenario. Green indicates precipitation increases, and brown, decreases. Hatched areas indicate that the projected changes are significant and consistent among models. White areas indicate that the changes are not projected to be larger than could be expected from natural variability. (Figure source: Walsh et al. 2014).

Table 14. Summer and fall temperature and precipitation projections used in BMGR Scenario 2. Values denote annual change in average from 1986-2005 and were drawn from 32 projections based on the CMIP5 high-emissions (RCP 8.5) scenario (van Vuuren et al. 2011), and downscaled, by team member Jeremy Weiss, to the region encompassing BMGR. Data: Reclamation and others downscaled CMIP3 and CMIP5 climate and hydrology projections (http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html).

Summer/Fall scenario: warmer, extreme uncertainty in rainfall amount, possible increase in torrential rainfall

SUMMER

	2011-2040	2041-2070	2071-2099
temperature*	+ 2.1°F (+ 1.2°C)	+ 4.8°F (+ 2.7°C)	+ 8.1°F (+ 4.5°C)
precipitation*	+ 2.1%	+ 8.8%	+ 7.1%

FALL

	2011-2040	2041-2070	2071-2099
temperature*	+ 2.3°F (+ 1.3°C)	+ 5.7°F (+ 3.2°C)	+ 9.4°F (+ 5.2°C)
precipitation*	+ 6.8%	+ 7.6%	+ 10.0%

*seasonal change in average from 1986-2005 for RCP8.5 32 model ensemble mean

(projection data archive at: gdo-dcp.ucllnl.org/downscaled_cmip_projections)

Increased warming in the atmosphere increases the capacity of the atmosphere to hold more water vapor—approximately 30% more if temperatures rise by ~5°C, as projected. Heavy summer and fall precipitation already generates substantial flood risks on BMGR lands, and increased warm season precipitation intensity has been recorded in studies from northern Mexico (Cavazos et al. 2008). The 3rd National Climate Assessment also projects doubling of heavy precipitation events in southwestern Arizona by the end of this century (Walsh et al. 2014).

We also considered regional energy impacts related to higher summer temperatures, using the recent example of the September 2011 blackout, during which the Yuma region, in which BMGR-West is located, lost power (FERC and NAERC 2012). Although driven by operational error and not a weather event, looking back on the impacts of blackout events such as this one nonetheless help in the assessment of possible future risks to interruptions in energy supply.

4.2.4. Assessing and prioritizing climate-related risks and opportunities

Using the success criteria described in Section 4.2.2, groups of participants generated an inventory of risks associated with each future climate scenario. Where possible, participants were asked to identify key sensitivities and critical thresholds (see Section 4.1.4 for a description of criteria for identification of critical thresholds).

Participants prioritized risks, based on the following criteria:

- Critical thresholds may be breached
- Systems highly sensitive to changes
- Decisions with long-term consequences
- Where “failure is not an option”

Participants also examined risks that might cut across functional groups (i.e., operations and training, infrastructure and transportation, natural and cultural resources). Team members compiled and presented a list (Table 15) of all the groups’ climate risks and participants voted on the priority risks identified across functional groups, in order to reach consensus on the issues deemed most critical to BMGR. Participants representing natural resources management constituted the majority of workshop participants; thus, the results of the voting exercise might be biased toward natural and cultural resources issues.

Table 15. Climate risks, in priority order, for BMGR identified during RC-2232 workshop discussions

Climate-related hazard	Risks to BMGR’s mission and success criteria
Extreme precipitation causing washout of roads on the range and highways	Access to resources, particularly in winter; cost of maintenance
System-wide destruction of riparian areas	Cascading consequences for the local environment
Species specific loss of home range habitat	Restrictions for use
Lack of mandate from all partners	Lack of good will beyond the fence line (BRAC issues), lack of coordination on actions that require coordinated responses
Dust storms	Visibility and safety, access to roads and air space for operations
Extreme heat	Border patrol, environmental impacts
Extreme heat	Performance of electrical equipment

4.2.5. Risk management

Workshop participants provided more detailed information on the current management of two top priority risks—(1) Road Washouts, and (2) Loss of Home Range Habitat and Individual Species—and brainstormed on needs, barriers, and opportunities to improving management in the face of climate change. The participants responded to the following questions:

- *Roles and responsibilities – who manages this risk?*
- *Existing guidance – what current plans are currently in place for this risk?*
- *Existing controls – what is the process for dealing with this risk?*
- *Needs – what informational/human resources/financial resources/monitoring is needed*
- *Barriers – what is getting in the way, or may get in the way of responding?*
- *Opportunities – are there benefits to acting now?*

Table 16, below, summarizes climate risk management discussions on these two key issues. With respect to the combination of extreme precipitation, flooding, and washout of BMGR roads: (a) roles, responsibilities, and guidance were straightforward; (b) maintenance tends to be reactive, and the effectiveness of best practice procedures are mediated by the needs of the Department of Homeland Security and U.S. Border Patrol, whose surveillance practices undermine road maintenance efforts, particularly in BMGR-West; (c) research and improved monitoring could improve preparedness and responses, provided that adequate funding is allocated; and (d) coordination and communication among BMGR and neighboring land holding agencies is a barrier and an obvious point of departure to improve preparedness and response to floods and their impacts.

With respect to climate change effects on species' habitat and home ranges, (a) whereas regulations are clear, assuming a stationary climate, guidance and process tend to break down with respect to the need for new assumptions commensurate with the prospect of climate change effects (e.g., ESA and NEPA assume a stationary climate); (b) participants, across multiple agencies, cited needs for improved data, more consistent interagency data protocols that would streamline data aggregation and consistency, and for research on the physiological limits and sensitivities of species; (c) key barriers to moving forward included funding and planning for long-term funding allocation, mismatch between the stationary assumptions of regulations and the dynamic prospects of climate change effects, and a lack of clear best management practices for a changing climate; and (d) participants noted opportunities for improved coordination, data and information sharing, and development of standardized methodologies for monitoring change.

Table 16. BMGR risk management summary related to road washouts, and loss of home range habitat and individual Species. Based on workshop discussions, February 2015.

Category: Roles and Responsibilities	**Road Washouts**	**Loss of Home Range Habitat & Individual Species**
	• On the range, Marine Corps Air Station-Yuma infrastructure and logistics personnel oversee the maintenance program. • Department of Homeland Security-Border Patrol also undertakes ad-hoc repairs, grading and dragging activities • BMGR-East uses contractors from Luke Air Force Base (civil engineers and pavement contractors) • Natural resources personnel, range wardens, and cultural resources personnel (BMGR-East) are also responsible for monitoring of the roads on the range • External roads are managed by Arizona Department of Transportation (ADOT)	• Regulatory enforcement is a required role • Policy, planning and reporting in BLM is overseen by NEPA planners • Interagency knowledge exchange is currently piecemeal
Category: Existing Guidance	**Road Washouts**	**Loss of Home Range Habitat and Individual Species**
	• Organ Pipe National Monument/Cabeza Prieta National Wildlife Refuge agreement with U.S. Border Patrol – Tactical Infrastructure Maintenance and Repair (TIMR) program • BMGR-East range maintenance contractors report on: number of miles maintained, dust control issues, washouts • Integrated Natural Resource Management Plan (INRMP) requires a National Environmental Policy Act (NEPA) assessment and public input process for new roads	• Regulatory enforcement is a required role • Policy, planning and reporting in BLM is overseen by NEPA planners • Interagency knowledge exchange is currently piecemeal

Category: Existing Guidance *continued*	• Arizona Department of Transportation (ADOT) monitors, maintains, and repairs state roadways (e.g., AZ 85). ADOT process calls for 25- and 50-year storm design. New roads require a NEPA process. They follow guidance from a Best Management Practices manual, with consultation • U.S. Border Patrol follows Best Management Practices for road maintenance • Marine Corps Air Station-Yuma is in the process of developing road maintenance funding priorities, based on a University of Arizona study, including mapping of soil and erosion in Barry M. Goldwater Range-West • Barry M. Goldwater Range and Cabeza Prieta National Wildlife Refuge sometimes closes roads during pronghorn fawning season	
Category: Existing Process	**Road Washouts**	**Loss of Home Range Habitat and Individual Species**
	• Maintenance tends to be reactive. When paved road washout occurs, plans are developed to create infrastructure to manage the future risks (e.g., retention pond). • Tohono O'odham Nation aims to stop grading roads further, as road grading concentrates water during storm events, leading to more vigorous flow and channelization	• Resource management plans include a priority list of species • ADOT acknowledge that their Environmental Management Plan has fallen between a gap • If new road construction takes place near conservancies, there is budget line for environmental management (e.g. wildlife underpasses) • Road maintenance tends to be reactive • Environmental management tends to be top-down, with little bottom-up input • It was acknowledged that plans need to be developed incrementally, based on the key concepts of "avoid, minimize, and mitigate"

Category: Needs	**Road Washouts**	**Loss of Home Range Habitat and Individual Species**
	• There is a need to assess how roads affect water flow, erosion, etc. LIDAR data could be used, but this is expensive and needs specific expertise and staff resources • Tohono O'odham Nation lacks road planning crew and funding – they are reliant on others, including the Bureau of Indian Affairs and ADOT • Financial and human resources are needed, particularly to fund hydrologists and civil engineers, planning (in Tohono O'odham Nation) with climate knowledge and best practice • Improved monitoring (more regular and high spatial density), particularly along the mountains • Understanding and monitoring of infrastructure thresholds could be improved (e.g. drainage pipe capacities)	• Knowledge and research gaps identified included: poor data and insufficient modeling granularity, uncertainty in spatial estimates • The physiological limits and sensitivities of species are largely unknown • Habitat modeling is also largely underdeveloped • There are regulatory needs, particularly around Endangered Species, specifically concerning the climate-driven loss of habitat. There needs to be a clarification of the ESA and the penalties that can be enacted if the range of available conditions for a species is lost due to causes outside the control of land managers (i.e., changes to climate and weather). • Clear definitions of terms would be helpful – e.g. extreme events (rather than climate change), resilience • Adding to the existing network of weather stations would enable spatial patterns to be discerned, and foster enhanced integration of observations into models • For compliance with Federal Environmental Regulations, there is a need for a "Environmental Clearance Officer" • Interagency agreements and information exchanges (including with Border Patrol), regarding species and habitat management, could be improved • It would be valuable to have an interagency agreement stating that climate change planning

Category: Needs *continued*		for habitat and species range changes is an important issue; to be effective, this needs to be coupled with a standardized methodology for data aggregation • Additional financial resources and a change in way funding is allocated, proportional to issue • There is need for greater consistency of political leadership, to promote buy-in • A sense of urgency, to address climate change risks, is lacking
Category: Barriers	**Road Washouts**	**Loss of Home Range Habitat and Individual Species**
	• Improve communication and coordination with Border Patrol (they are not always included in interagency discussions; key issue: they don't usually comply with agreements) • Communication and coordination between agencies could be improved	• Fluctuations in funding, and poor redistribution of funds, can be very disruptive to longer-term programs. • Planning timescales (long-term) are misaligned with annual budgetary plans • Limited knowledge and understanding of management options and best practices • Regulations, such as NEPA and ESA, slow things down, because the terminology focuses on "Net gain" – there is concern about over-regulation of individual species when actions can be taken to enhance habitat types and general conditions. This is the conflict between managing on a species-by-species basis (ESA) vs. a coarse management strategy for promoting entire ecosystems. NEPA and the ESA are helpful in some contexts, but can significantly slow down action on others. • Undesignated Vehicle Routes (particularly at Organ Pipe National Monument) result in litigation, lawsuits, and increased bureaucracy.

		• Finally, aesthetic buy-in from public is limited – this is an advocacy issue
Category: Opportunities	**Road Washouts**	**Loss of Home Range Habitat and Individual Species**
	• Tohono O'odham Nation has a MOU with Luke Air Force Base • There are opportunities to improve data sharing and identify common issues	• There is an opportunity to improve cooperation and agreements between agencies, particularly with respect to the development of standardized methodologies • A central repository for data may be useful; it was acknowledged that this would be costly to set-up and would require dedicated ownership and maintenance • It was recognized that it is beneficial that almost all the land in the BMGR area is federally managed (with limited private land owners); thus, "you know who's in charge!" • To the degree that the federal government acknowledges climate change as an important issue, there are prospects for funding

4.2.6. Discussion

In the BMGR case study, our team applied the same participatory climate change risk management framework that we used at NBC. We supplemented the BMGR climate change risk management workshop with pre-workshop meetings and webinars; these were an important part of fact finding, which helped us understand the climate risk context at the BMGR installations. In particular, we learned about the importance of beyond the fence line land management to the success of land and natural resources management to maintain BMGR's missions. We found that the participatory workshop worked well, to efficiently gather information on climate- and weather-related risks, and to establish, with installation personnel, the cause-and-effect linkages between climate and impacts. The participatory workshop with BMGR personnel also confirmed the efficacy of our risk assessment framework in connecting imminent and long-term risks (e.g., flood risks and roadways, endangered species habitat and range shifts), which fostered concrete discussions about climate change risks to the installations.

Perhaps due to the fact that our service liaisons were natural resources experts, a large part of the BMGR climate risk discussion focused on vegetation and wildlife management. BMGR has already made strides toward adapting to climate change, in multiple ways:

1. through incremental adaptations, such as a regional semi-captive breeding program for Sonoran pronghorn, and the development of wildlife waters on installation lands, in order to ensure the survival of this endangered species;
2. the BMGR Integrated Natural Resources Management Plan is grounded in the philosophy and practice of adaptive management, which puts BMGR personnel on the fast track to adopting practices suitable to climate adaptation planning and implementation;
3. installation offices already use reverse-osmosis water treatment—an important adaptation for sustaining operations in the hottest, driest part of the Sonoran Desert in the U.S.;
4. BMGR has a long history of cooperation with neighboring land managers, including Native American tribes, federal and state agencies, departments of transportation, and others; this is a good base to work from, to improve adaptive capacity and preparedness, provided that knowledge exchange pathways are maintained, that they cut across functional activities and are not stove piped within narrowly defined concerns—which can lead to development of maladaptive strategies.

Our experience at BMGR confirmed the importance of natural resources management staff, including service liaisons and civilian staff, to provide institutional knowledge and expertise on identification of a portion of the array of climate-related risks to the installations.

We were unable to implement our semi-quantitative risk assessment at BMGR. This was due to the lack of an emergency and risk management guidance document similar to Navy Installation Emergency Management Program Manual (CNI 3440.17), Standard 4. Also, participation in workshops and follow-up focus groups lacked personnel intimate with details on infrastructure and operations; thus, our risk assessment may be biased toward natural resources and resource monitoring concerns, such as vegetation and wildlife management, and the condition of roads that provide monitoring and assessment access to natural and cultural resources personnel and contractors.

Personnel mentioned opportunities to improve adaptive capacity and climate risk management through proactive climate services, such as coordination on data, monitoring networks, and protocols for streamlining interagency data aggregation and consistency. BMGR is an example of military operations in an environment so extreme that the incremental change in risks of future extremes, as a result of climate change, may only require only small adaptations to the training mission, but an increased ability to anticipate large adaptations with respect to natural resources management.

4.3. Case study results: Fort Huachuca

4.3.1 Background

Fort Huachuca is a 30,756 ha (76,000 acre) Army installation located in southeastern Arizona at the Northern end of the Huachuca Mountain Range, 24 km (15 miles) north of the border with Mexico. Average rainfall is 392.9 mm (15.5 in) with an average summer temperature of 23.8 C (74.9 F) and average winter temperature of 9.4 C (49 F). The base elevation of the Fort is 1,199 m (3,934 ft) ranging up to more than 2,225 m (7,300 ft) along the southwestern border with Coronado National Forest and up to 2,885 m (9,466 ft) on Miller Peak located approximately three kilometers (two miles) south of the Fort.

The Fort supports approximately 14,000 active duty soldiers and their families and 5,000 civilian employees. Infrastructure is concentrated at the center of the Fort where the forests and woodlands of the Huachuca Mountains transition to a more open semi-desert plain. The location of the Fort at the base of the Huachuca Mountains is a nexus of urban and natural landscapes, with a civilian population of approximately 43,000 along its eastern border in the city of Sierra Vista, a largely unpopulated national forest with designated wilderness to the south and west, and private and state range lands to the north. The primary surface water source is the Upper San Pedro River, which is proximate to both the Fort and the community of Sierra Vista. Forests of the Huachuca Mountains outside of the Fort are under the jurisdiction of the Coronado National Forest and are home to some of the highest plant and animal diversity in the region, including the threatened Mexican Spotted Owl (*Strix occidentalis lucida*).

The Fort was established in 1877 as Camp Huachuca to counter the Chiricahua Apache Tribes and to secure the Mexican border. The primary roles of the installation have evolved over its 140-year history where it is currently the home of the U.S. Army Network Enterprise Technology Command (NETCOM), U.S. Army Intelligence Center, Army Military Auxiliary Radio System (MARS), the Joint Interoperability Test Command, the Information Systems Engineering Command (ISEC) and the Electronic Proving Ground. Along with its function in support of the mission of the Department of Defense, the Fort and surrounding landscape are under the jurisdiction of the Department of Homeland Security and Drug Enforcement Agency.

We were asked initially to help design a climate change *charrette* at Ft. Huachuca by the principal investigator of the Army Corps Research and Development Center (ERDC) during our the initial SERDP orientation meeting in November 2012. Rather than develop our own independent engagement, we agreed to work with the ERDC; therefore, the format of the engagement did not directly parallel that of the subsequent risk assessment workshops at other

installations.

Our SERDP team worked with the ERDC-CERL team to adapt a NASA climate change adaptation assessment framework for a 2 day engagement on Ft. Huachuca. The charrette was built around two collaborative breakout sessions between base staff and scientists. Personnel for these sessions were organized into three separate groups consisting of personnel within three broad categories of expertise; 1) land; 2) air; and 3) electromagnetic spectrum operations based on recommendations by Ft. Huachuca staff.

The first round of breakout sessions was designed to quickly narrow discussion to a single mission-related asset or function and then follow three guided steps:

1. Focus on vulnerability of the asset as a function of climate.
2. Overlay with climate projections, timing, and uncertainty.
3. Discuss magnitude of consequence and the installation response.

The second round of breakout sessions was curtailed due to inclement weather and base closure to non-essential personnel but was designed to address adaptation directly through a series of steps to:

1. Document existing adaptation strategies to climate impacts identified.
2. Describe existing planning processes.
3. Develop new strategies.
4. Categorize the type of strategy.
5. Name the primary implementer.
6. Name all stakeholders inside and outside the installation fence line.
7. Estimate an implementation cost.
8. Describe where and how adaptation strategies integrate into existing plans.

We used the primary risks identified in the initial round of breakout sessions to re-engage with installation personnel in the Environment and Natural Resources Division (ENRD), given that it represented an excellent opportunity to assess interactions and competing priorities over a diverse landscape with multiple management objectives for military and civilian uses. Recognizing the challenges of decision making on such a diverse landscape, resource management staff at the Fort have a history of science engagement and proactive management to meet regulatory requirements and protect against perceived threats. For example, the fire management officer at ENRD has a regular program of seasonal controlled burning as a fuel reduction measure near target ranges to mitigate against fire spread to nearby training infrastructure and on-base housing.

In the past decade heightened concerns prompted by a recent large wildfire near the Fort (Figure 40a) and severe post-fire flooding affecting the nearby community (Figure 40b) prompted ENRD biologists and wildlife managers to actively seek outside scientific input to address perceived risks.

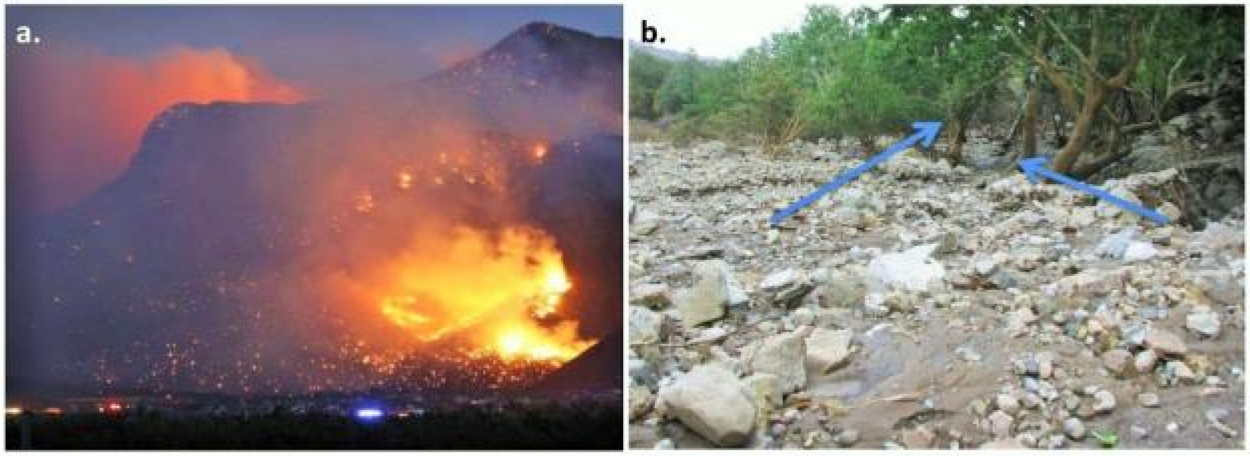


Figure 40. Monument fire in the Huachuca Mountains in 2011 (a) and post-fire debris flows in Marshall Canyon (b). Arrows in (b) identify the confluence of Marshall and Miller Creek completely infilled with rock and debris following a series of monsoon storms weeks after the Monument Fire. Photos courtesy of USA Today (a) and Dr Ann Youberg, Arizona Geological Survey (b).

In the months prior to our engagement the director of ENRD commissioned a study to assess the potential outcomes of a fire similar to the 2011 event on endangered Mexican Spotted Owl habitat. The study found that proactive implementation of fuel treatments near owl habitat could significantly reduce short-term fire risk (Figure 41). However, this work was specifically designed to address current conditions and potential short-term mitigation actions without consideration of changing climate conditions.

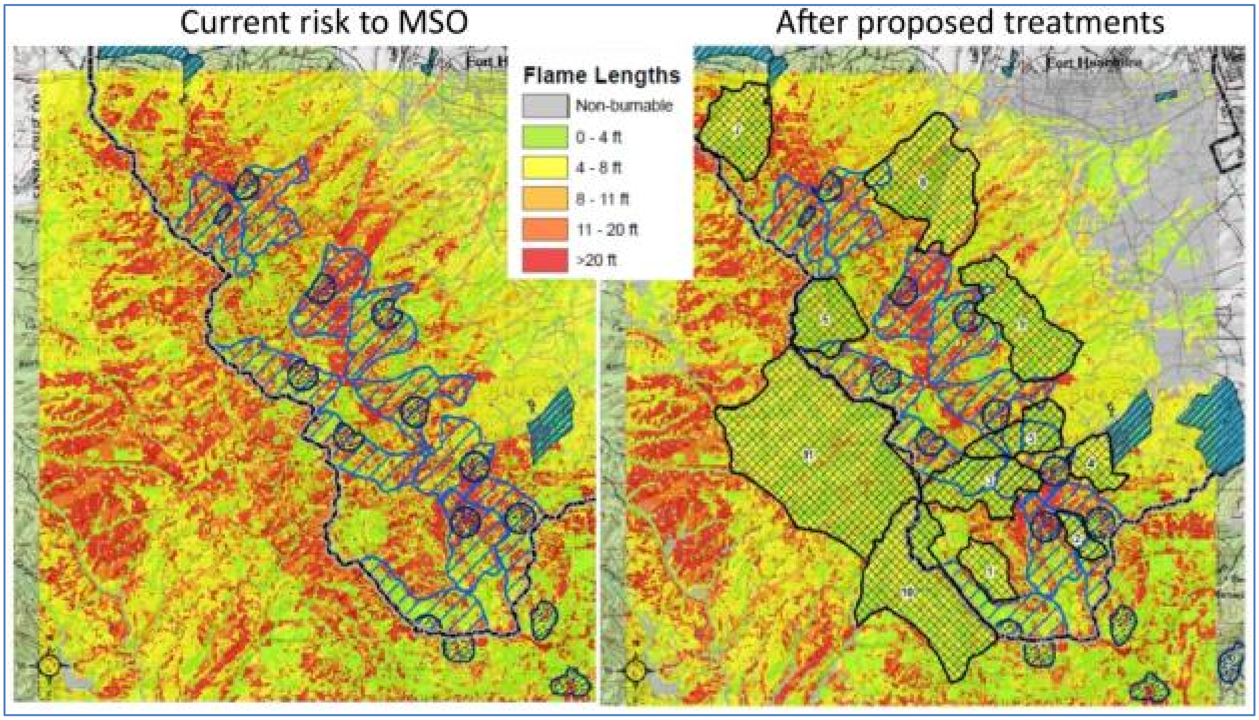


Figure 41. Modeled flame lengths in MSO core areas under current climate, with and without fuel treatments. Figure courtesy of LaWen Hollingsworth USFS Fire Modeling Institute.

We used the concerns of changing fire conditions and its effects on infrastructure, flood risk, vegetation, and species of concern as entry points to discuss how future climate could serve to mitigate or exacerbate the current level of risk.

4.3.2. Exposure to current and future climate changes

In our initial meetings with Natural Resource Management personnel we discussed the implications of each of the risks identified in the charrette and the types of information that would be useful to inform decision making. Because three of the four primary risks were directly influenced by fire, ENRD staff agreed that we should focus our engagement on exploring how climate change is likely to influence fire and vegetation in the mountains abutting the Fort. Implications from these projections could then be used to assess risks to natural systems, infrastructure, training, and mission operations.

With the help of natural resources staff we developed a series of initial research questions that could be used to explore mitigation options.

Primary questions developed during our initial engagement were:

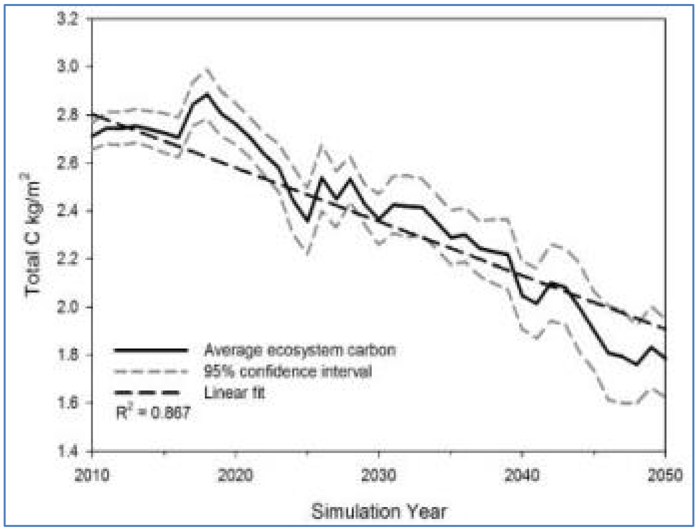
1) How might climate change affect the frequency and severity of future fires and how would this affect vegetation?
2) If fuel treatments were done, how long would they remain effective?
3) Would fuel treatments on DoD lands protect against fire spreading from other ownerships?

After an assessment of the available data on site and research tools available from national sources, we decided to use a landscape simulation approach incorporating current vegetation, simulated fire, simulated thinning treatments, and both historical and future climate scenarios to address these questions. Our goal was to produce results that would allow resource managers and garrison staff to assess a range of possible future outcomes and mitigation actions to help integrate climate projections into the current risk matrix used to address both short and long-term decision making. We worked directly with ENRD wildlife biology and forestry staff to determine the climate projection scenarios most appropriate to use to understand potential climate effects on the risks identified. After a discussion of the available suite of scenarios from the most recent generation of GCMs (CMIP5), NRM staff suggested we use the "business as usual" scenario (Relative Concentration Pathway 8.5) to assess potential impacts without active mitigation of greenhouse gas emissions.

We shared initial simulation results with ENRD staff to make sure that the products from our research collaboration would be useful for assessing risk and aiding decision support. For example, in our initial simulations of fuel treatments, we limited the rate of fuel treatment activity to the number of acres that could be treating annually using existing resources at the installation. Initial results showed little effect of the relatively slow rate of fuel treatments. On the suggestion of the ENRD Forester, we increased the rate of fuel treatments five-fold to reflect the potential of additional resources allocated to the fuel thinning effort. The simulated increased rate of fuel treatment produced a measureable result and provided potential justification for additional resource allocations to proactively influence the trajectory of the landscape. This significant conclusion was of great interest to the ENRD Forester and his staff? Similarly, following a demonstration of potential changes to the landscape from fire and climate, the ENRD Hydrologist agreed to help us to simulate changes to surface flows under projected climate conditions. The initial results, produced for the ENRD Forester and Wildlife Biologists, served to engage the installation hydrologist, who then furnished us with specific data regarding a 2014 flood event in Garden Canyon. These data were then used as the design storm to simulate a similar rain event in neighboring Huachuca Canyon where there is a much greater concentration of sensitive infrastructure.

4.3.3. Climate and fire risk modeling results

On the simulated landscape, forests of the Huachuca Mountains underwent significant shifts in forest biomass, species distributions, and patterns of fire over 50 years of projected future climate (which RCP?). Forests historically dominated by large mature conifers underwent a significant range contraction, receding to the few cool moist riparian areas. These forests were largely replaced within 30 years by smaller Madrean evergreen oak and shrublands, historically present only at lower elevations. In all scenarios with or without fire or fuel treatments landscape scale plant biomass was significantly reduced over fifty years of projected future climate. This is represented in Figure 42 as a continuous decline in total ecosystem carbon, suggesting that vegetation at the Fort that has remained relatively unchanged over the past century of use by the US Army is likely to transform dramatically over the coming decades.



Simulated fire activity (fire size and frequency) increased for the first three decades but then feedbacks from fuel limitations resulted in an eventual reduction in fire size for the last two decades of the simulation (Figure 43).

The initial increase in fire activity threatened endangered species habitat and facilitated conversion of forest to shrubland.

Figure 42. Change in simulated total average ecosystem carbon (kg m^{-2}) for the Huachuca Mountains under the CanESM2 Global Climate Model projection of RCP 8.5.

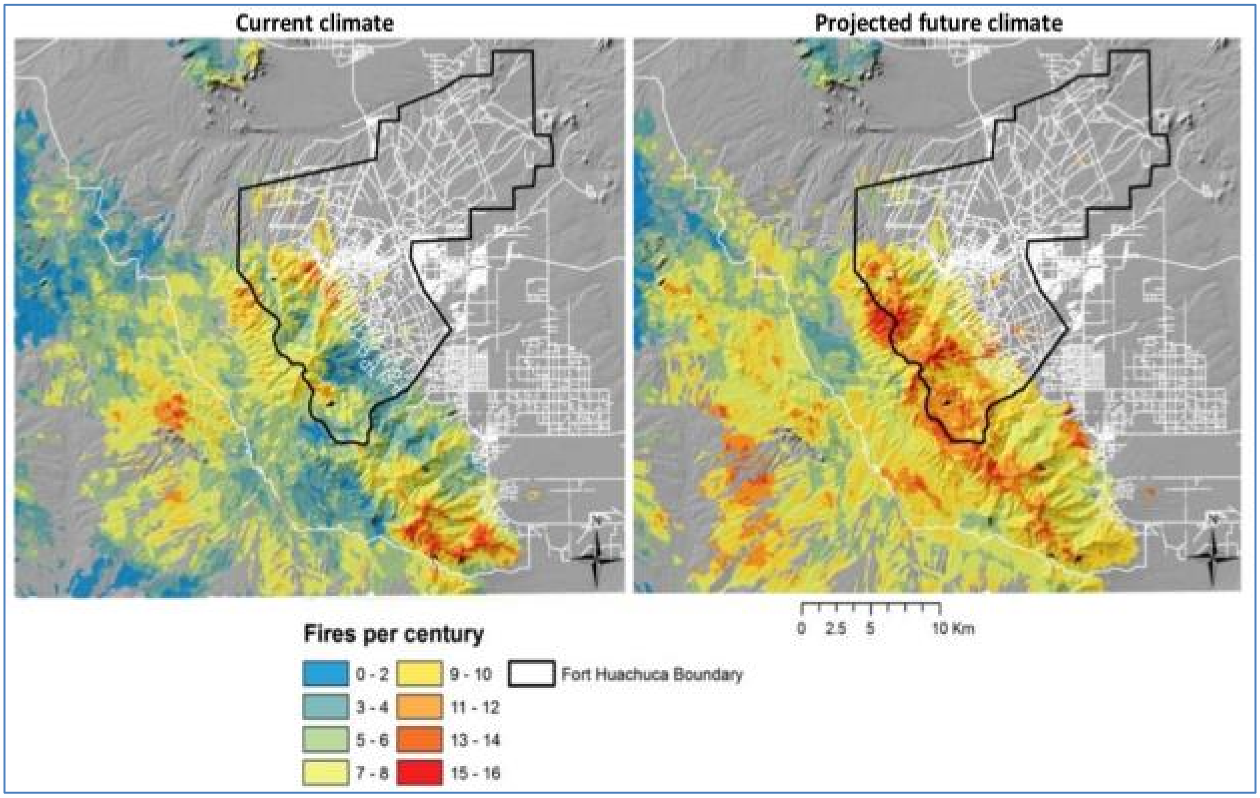


Figure 43. Simulated change in fire frequency under projected future climate. Note the increase in fire count in the future projection occurs primarily in the first three decades of simulation (near future).

Although the simulated increase in fire activity was temporary, fire severity (tree mortality caused by fire) increased continuously throughout the simulation period (Figure 44). The increase in fire severity is a feedback from the change in vegetation type from large fire resistant conifers to dry shrubby species capable of re-sprouting from their roots following burn over from fire. The increase in fire severity has direct implications for soil erosion, post-fire debris flows, and change from forest and woodland to sparse shrub vegetation.

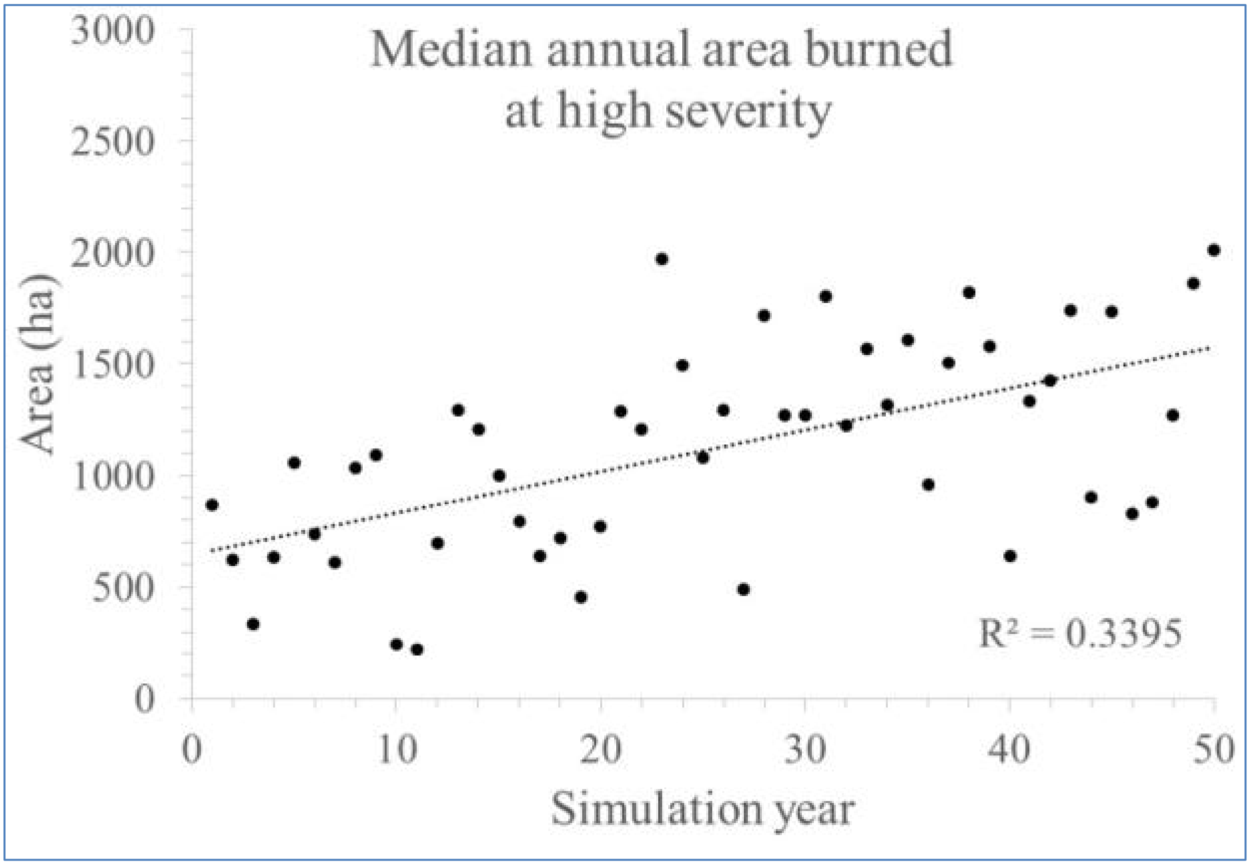


Figure 44. Simulated change in area burned at high severity over five decades of projected future climate. Year zero is equivalent to climate year 2010.

Fuel treatments demonstrated the potential to reduce the risk of high-severity fire in and around protected Mexican Spotted Owl breeding sites but did not appear to reduce fire frequency during the first 20 years of the model simulation. Simulation of a secondary thinning treatment at year 20 further reduced the risk of high severity fire and may also reduce the risk of fire spread into breeding sites for an additional 1-2 decades. Fire allowed to burn in conjunction with thinning treatments appeared to contribute to persistence of forest species diversity by varying the age classes and patch sizes of individual stands. The combination of thinning treatments and fire may also have served to reduce competition among trees, allowing larger, older trees to persist on the landscape longer than in forest subject to total fire exclusion. Importantly, fire management either through direct fire suppression or fuel reduction treatments did not slow the rate of landscape-scale biomass loss or changes to species distributions.

4.3.4. Post-fire flood risk

The risk of acute flood events in the simulation watershed increased significantly with each decade of simulation. While climate models have low confidence in projected changes to monsoon storm activity over the next several decades, using reference storm conditions familiar to the installation allowed us to simulated changes to runoff as a function of simulated landscape change and fire activity (Figure 45). The continuous increase in the size of high severity burn patches translated into greater risk of high volume flooding with each successive decade of simulation (Figure 46).

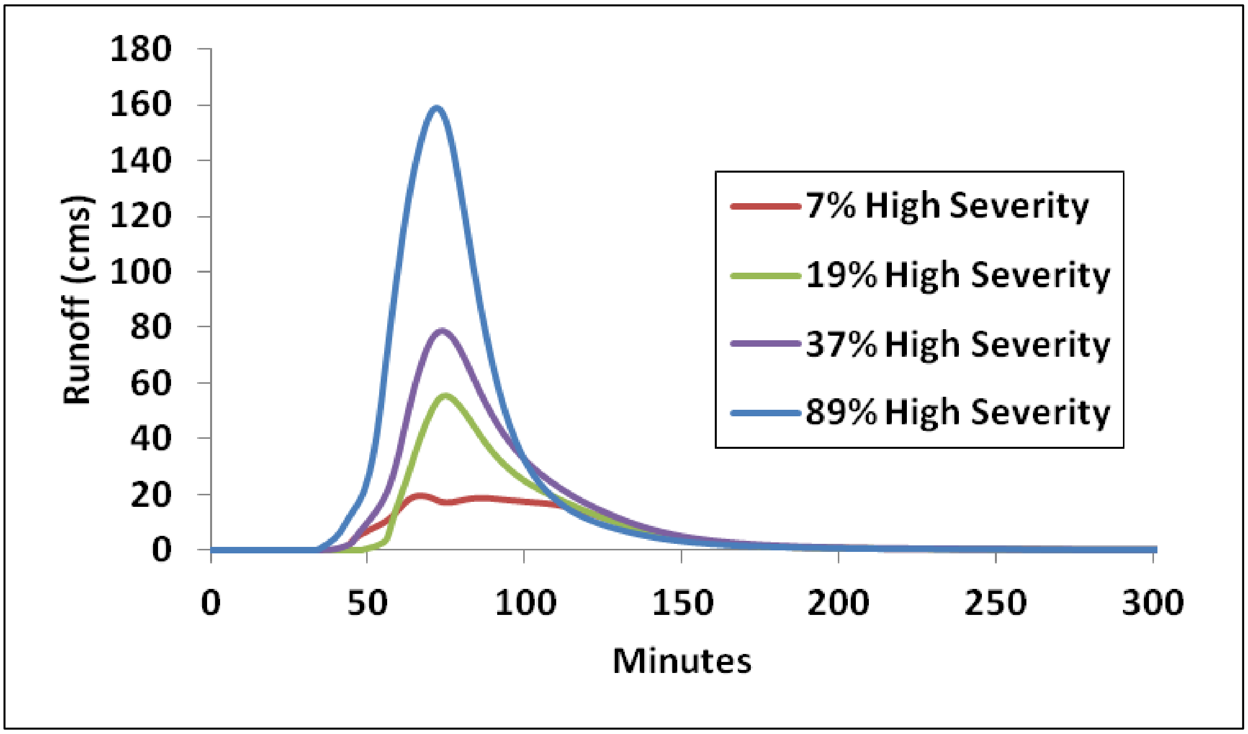


Figure 45.Comparison of hydrographs at the outlet of Huachuca Canyon. This compares the magnitude of watershed runoff response to the percentage of the watershed affected by high severity fire assuming equal rainfall events.

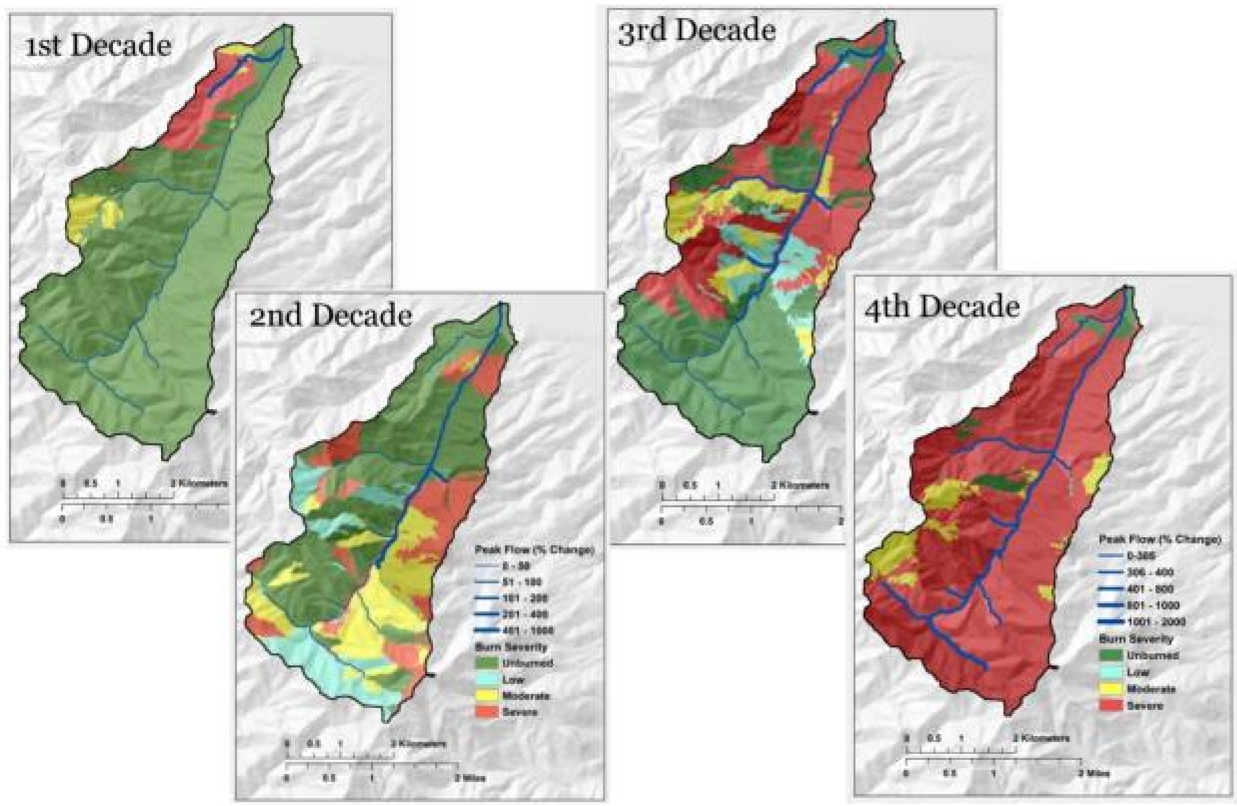


Figure 46. Spatial representation of increasing surface flows as a function of greater area burned by high severity fire (red) in the Huachuca Canyon watershed. Decades represent example fire effects during successive decades of simulation.

The downstream implications for these changes to vegetation and fire manifest at the outlet of Huachuca Canyon, where the high density of historic buildings and other sensitive infrastructure are at increased risk. Projected extreme surface flows resulting from large patches of high-severity fire, similar to those observed in Marshall Canyon in the 2011 Monument fire, suggest that culverts, bridges, roads, and buildings located near the Huachuca Creek channel would be subject to several fold greater surface flows than the roads and bridges damaged by the 2014 Garden Canyon flood event (Figure 47).

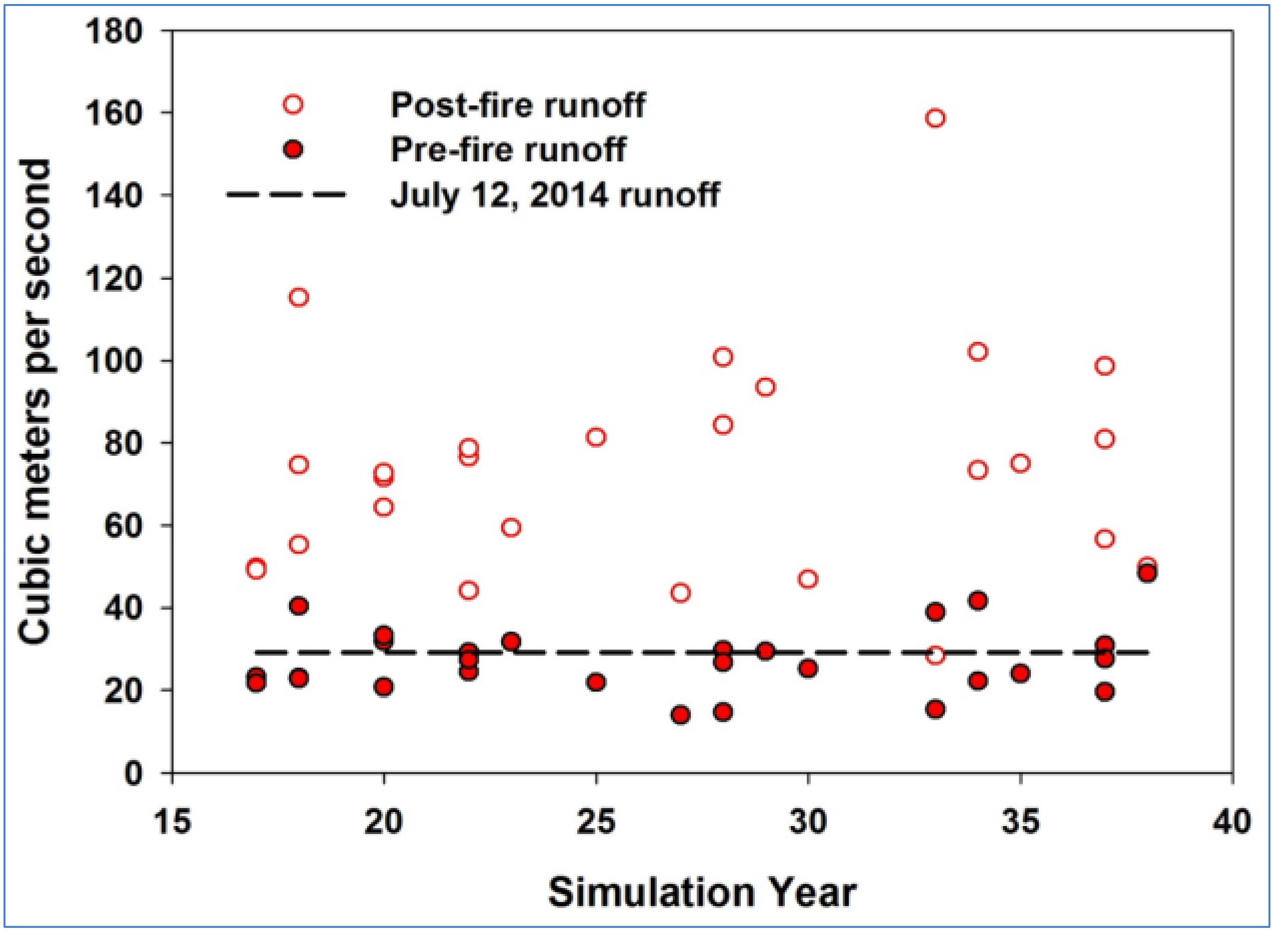


Figure 47. Simulated surface flow rates at the outlet of Huachuca Canyon with and without fire in the watershed. Solid dots represent flow rates without fire, open dots represent flow after fire, and the dotted line is the flow rate following the 2014 Garden Canyon design storm.

4.3.5. Discussion

Until we were able to engage with ENRD and other installation staff, we were limited in our ability to engage with installation-level decision makers to discuss the details of climate adaptation decisions. However, having a series of locally tailored climate risk outputs to discuss with these higher-level officials made the conversation more relevant to the commanding officers and gave us better insights into the capabilities of the installation to integrate and act upon climate risk information.

The direct engagement of Fort Huachuca garrison staff in designing the climate change simulation experiments allowed us to integrate the real-world information, opportunities, and limitations of installation-level operations with our climate change risk assessment and analysis process. The iterative process used in the coproduction of knowledge with base personnel was informative to us as researchers and to the installation staff to understand the current state of climate modeling capabilities and limitations and how to access this kind of information. Much of our work was designed to expose operations personnel to resources available for understanding climate risks and how mitigation actions may or may not influence specific

outcomes. The reports generated from the climate and fire and post-fire hydrology climate change studies provided the impetus for us to engage directly with the Garrison Commander, Deputy Commander, and their staffs to discuss the implications of our finding and to pose a series of our own questions regarding how this type of information can be used and integrated into current and future planning for climate change adaptation.

4.4. Framing climate change risk in the context of current threats to operations and mission support

4.4.1. Background

DoD installations are established and managed with mission in mind. Anything that distracts from achieving that central purpose is necessarily secondary. Thus, it is not surprising that climate-related issues do not take center stage in the attention of most base commanders on a daily basis. In contrast to more central issues of training, facilities, and personnel, climate issues are perceived as too diffuse, remote, and uncertain to merit action. This focus on the here-and-now is completely understandable, given the multiple demands of base management. Future projections of changing temperature or precipitation regimes, shifts in species distributions, or climate-driven changes in biotic communities cannot be expected to compete successfully for the attention of base management compared to roads, buildings, utilities, vehicles, training programs, technology, community relations, environmental regulations, and military and civilian personnel.

Not all climate-related risks are diffuse, remote, and uncertain, however. As discussed elsewhere in this report, many coastal installations are already experiencing the effects of rising sea level first hand. Water supplies, especially in the West, are increasingly dependent on over-tapped groundwater sources, or on surface flows of streams and rivers that are losing annual flow as snowpack is replaced by winter rains and accelerated spring runoff. Summer temperatures at many bases are exceeding safety limits for outdoor training with increasing frequency. Storm intensity and magnitude of wildfires are increasing. All of these are manifestations of interactions of the climate system with hydrologic and ecological systems, and have direct, if progressive, impacts on communities throughout the country.

4.4.2 Our approach

In this project we explored cases where the climate-related risk was imminent, and where the effects are potentially more irreversible. Base staff and COs are responsive to addressing immediate and near-term risks to operational capacity and integrity. Gauging climate-related risks in the context of recent or near-term threats, and articulating the level of magnitude of the threat in relation to past or imminent threats provides staff with a scale at which they can judge the prospects for successfully addressing these risks. We hypothesized that integrating climate change risks into the current decision matrix by linking projected threats to current or past threats creates more active engagement by focusing on here-and-now challenges. Addressing specific issues now can help build capacity to address climate change adaptation into future planning and risk management processes over time, and build interest in science-based solutions. An

operational change in response to a specific climate risk can promote consideration of climate change risk into associated planning and will help to stimulate incorporation of climate change risk throughout the planning process.

4.4.3. Observed and projected fire and fire-related flooding risk

We tested this hypothesis in the most detail in our engagements at Fort Huachuca (FTH) and Naval Base Coronado (NBC). In each case we began with our own background research, followed by interviews with base operations and technical personnel. This led to co-identification of specific climate-related concerns that could affect (or are affecting already) base operations in the near term. We used a combination of detailed remotely-sensed and ground-truthed vegetation mapping, fire modeling, and hydrologic modeling, in iterative consultations and discussions with installation personnel—a co-production of science approach (Meadow et al. 2015) to contrast modeled current fire risk with projected future fire risk. This applied research yielded fundamental science insights, as well as multiple, well-documented anecdotes to support hypotheses about the aforementioned engagement method (Figure 48).

Both installations have experienced fire exposure recently. In 2011, the Monument Fire burned across the eastern slopes of the Huachuca Mountains which overlook FTH, extending out into the outskirts of the city of Sierra Vista and neighboring communities, including part of the base.

Figure 48. Image of the 2011 Monument Fire that burned across the eastern slopes of the Huachuca Mountains overlooking FTH.

During the subsequent summer monsoon season, heavy (although not unusual) rains precipitated dramatic floods and debris flows in several east-flowing canyons, including Marshall Canyon near the Base. In the case of NBC, Camp Michael Monsoor (CMM) and Camp Morena, the inland training facilities, are located in landscapes dominated by chaparral ecosystems, which are prone to large, very high severity wildfires, although none had occurred in the immediate vicinity of the base in several decades.

Base leadership was well aware of these risks, although day-to-day concerns naturally deferred action. Nonetheless, in both cases base managers and leadership were willing partners in our exploration of potential elevated risks, because they recognized the reality of the potential hazards. By engaging with management and leadership around tangible hazards that had already been experienced, it was easier then to open the door to dialogue about other emergent climate-

related risks and potential adaptation strategies. Partnering directly with base management created greater co-identification of risk and therefore greater value and utility and more effective engagement.

4.4.4 Linking immediate management priorities to long-term climate exposure

DoD personnel and resources at all levels of the organization are already fully committed to fulfilling the agency's existing missions. Thus, developing engagement about future risks can be challenging because they appear to distract from current, immediate mission focus.

Quantifying place-specific climate change risk builds awareness of pervasive effects of climate and increases capacity to incorporate climate change adaptation into other planning and risk management processes. Without placing future risk into the context of current concerns, climate change messages appear to be too abstract for DOD personnel to devote their limited time, attention, and resources. Base managers (and others) must first understand "how will this affect me?" This is in fact a fundamental lesson in climate communication studies more generally: engaging people in participatory and deliberative decision making that addresses their own experience directly, and addresses their beliefs about their self-efficacy (e.g., that the actions that they take today in their operational job duties will have an impact on a desired outcome), and that motivates constructive engagement—rather than engendering fear or indifference—is an effective way to get their attention about issues that are perceived to be in the distant future (Bostrom et al. 2013; Frumkin and McMichael 2008; NRC 2010). Addressing immediate concerns facilitates engagement, promotes a sense of efficacy, and garners interest in continued engagement and action.

4.4.5 Discussion

The immediate needs of base management, maintenance and operations are necessarily the focus of DoD installation budgets. Climate change in this context is only a background issue, not mentioned explicitly in most base operation plans, or if it is mentioned it is often discussed as an issue for the remote future. Consequently, even if a base commander is open to climate change adaptation actions, such work may not be included in operational budgets. None of the natural resources personnel with whom we interacted were aware of funded programs for adapting to climate change risks related to wildfire at their installations. Even at FTH, where the fire-flooding risk was tangible, only a relatively small amount of funding is allocated to fuels treatments and prescribed burning, and the majority of needed prevent work is accomplished through partnerships with adjacent landowners, including the US Forest Service and The Nature Conservancy.

Installations are the "front lines" of climate change for DoD. The articulation of climate change policy at the national DoD level has been helpful for legitimizing a focus on the general topic, but to date these pronouncements and guidance have not been accompanied by funding appropriations. Consequently, while understood as important, climate adaptation is generally not highly prioritized until it can be tied directly to imminent threats. To most base managers we worked with, national DoD policy and guidance for climate change adaptation is an unfunded mandate. Many personnel with whom we worked indicated that they would be happy to undertake climate adaptation and mitigation measures (e.g. conversion to electric vehicles, solar electric and hot water installations) if some funding stream was available for this purpose.

4.5. The Roles of Leadership and Institutions

Climate change models project numerous long-term challenges to the ability of Department of Defense (DoD) installations to complete their missions. Through semi-structured interviews we aimed to better understand the role of leadership and ways to incorporate climate considerations into longer-term decision processes, training, and education initiatives. Leadership is a critical component of managing climate risks (in the context of an array of other issues), yet based on our research, it appears that the frequent turnover of leadership in Department of Defense installations may undermine efforts to ingrain climate change considerations into operational decision-making. In order to advise DoD on incorporating climate change adaptation into standard operating procedures, the multiple scales of DoD leadership and decision making need to be understood as well as the organizational behaviors in place.

4.5.1. Background

The purpose of this aspect of our research was to identify the barriers to including climate change adaptation within various service components, as well as to highlight the incentives needed to increase the likelihood of DoD success at embedding climate change considerations. Incorporation of climate change considerations into organizational operations requires consistent leadership and concomitant institutional support. Without support at all levels of governance, climate change adaptation may lose traction in the dynamic culture of DoD decision making. We also recognize that imminent risk is central to rapid incorporation of climate change in risk management decisions, but there may be other ways to incorporate these considerations into facility planning and implementation, through the development of strong region-wide and installation-specific partnerships over various time horizons. Our work here addresses concerns about the connections between near-term management decisions and decisions affected by plausible long-term climate futures through analysis of the institutional norms in place at military installations.

The primary objective of the interviews was to report on how tools for adapting to climate change initially identified through the site specific case studies at NBC, FH and BMGR may be translated from the academic setting, to the military procedural format, to *mainstreaming* into DoD procedures. By surveying military personnel from various branches and service components to establish the unique needs and culture of military leadership, we aimed to foster a greater understanding of the institutional setting through which military training and education, in the context of including climate change and adaptation leadership, may occur or be planned for in future research. Potential benefits of this project include a better understanding of climate change adaptation tools and resources valued and desired by DoD facilities and decision makers.

Not surprisingly, recent literature indicates that organizational culture influences the behavior and responses of military organizations and has been identified as an important aspect of military decision making (Terriff 2006; Kapucu 2011; Jungdahl and McDonald 2015; Clark 2016). Identifying opportunities for insertion of climate change science, adaptation and mitigation within DoD hierarchical command structures therefore requires understanding of the hurdles that various levels of leadership may face when attempting to mainstream climate change adaptation. To become more familiar with the specific duties and decisions linked to day-to-day operations,

the UA team conducted a series of 16 ethnographic semi-structured and open ended interviews with military personnel conducted between the months of August 2016 and November 2016. Questions asked of respondents were also derived from discussion of outcomes of previous project debriefings and workshops, including the SERDP Cross Project Workshop held in March 2016.

The ethnographic approach examines behavioral norms, perceptions and personal experiences as part of the data collection process (Neuman 2000). As a result of the interviews conducted, the research team was able to uncover repeated themes and perceptions that provide insight beyond our onsite case studies, including opportunities for integrating climate change adaptation within existing DoD frameworks. To frame our inquiries, a core set of informal hypotheses and indirect constructs were explored with DoD personnel at various service components, including installation leadership at various facilities. Comparing and contrasting the perspectives of "top-down" and "bottom-up" interview participants was the initial ambition of the project. However, access to individuals in a statistically significant sample across the DoD hierarchy was difficult to attain. Inviting active military personnel at various installations, within different commands and service components to participate in interview sessions did, however, provide unique opportunities for the UA research team to hear individuals express their working knowledge of the role of leadership and institutions in disseminating and translating information.

Data collected during interview sessions was coded, de-identified and analyzed in compliance with human research protocols to protect the identity of participants. Only coded and de-identified transcription was used for analyzing the text, and solely for broad and generalized reporting and manuscript purposes. The final summary of findings complies with human subjects protocol and therefore does not contain any identifiable data that could put the respondents at risk. The synthesis of broader lessons learned from the combination of these interviews and field work over the duration of the larger RC-2232 project ultimately provided the team with a robust grasp of daily, real-world, and on the ground issues faced by DoD personnel.

Convenience and snowball sampling techniques are a critical part of ethnography (Delamont, 2004; Creswell 2012; Spradley 2016). Ethnographic techniques were used to recruit respondents and conduct informal interviews. Some participants who were already indirectly engaged with the project were invited to participate in this additional facet of our research. Responses therefore reflect the experiences, insights and perceptions of a) individuals who may have in the past worked with, or are currently familiar with the UA SERDP project team to some degree b) individuals who expressed a desire to participate in this research during the project cycle or c) individuals that were suggested by others aware of the SERDP project and were then invited to participate voluntarily and confidentially. The population interviewed (*n*=16) offers viewpoints from various command levels within the U.S. Army, Navy, Air Force and Marines. Combined, these respondents offer 308 years of active duty experience with an average of 22 years of service and having various numbers of transitions, promotions and service component duties; all of these individuals were commissioned officers.

The procedure for human research for this project included an introductory email inviting subjects to voluntarily participate in a semi-structured phone interview. Respondents represent *individual* opinions of people who are a) currently working as active military personnel b) retired

military personnel c) military contractors or d) military liaisons or e) military professors or ROTC military instructors. In most cases the subjects were indirectly involved with the project and only directly involved with the project through the survey instrument. Key topics of the survey included the translation and dissemination of scientific information related to climate change and the resource needs of decision makers.

4.5.2. Barriers and Opportunities

Through the interview process the team identified a set of barriers to climate adaptation that were also dominant themes in other aspects of the project.. Most notably, budgetary constraints and frequent rotation of personnel were frequently cited barriers for implementing climate change adaptation. As budgets tend to drive actions, we noted that inadequate information about the true cost of climate impacts was a significant problem – given that there is significant evidence in other applications that proactive investments in risk management strategies can be far less expensive that the cost of the impacts that are avoided. This leads to the a conclusion that better economic information about the costs of impacts vs. the costs of adaptation would likely provide significant incentives for at least some base leadership to engage in adaptation efforts with more enthusiasm.. As noted in the pilot studies, adaptation was not a priority when compared to immediate and pressing strategic, operational and budgetary concerns. Access to relevant climate information at the right scale was another noteworthy concern. Similar to the findings of the RC2232 installation level pilot studies, respondents also reported that multiple disconnects exist in on-base? cross-departmental communication and planning efforts; assignment of responsibilities for implementing and managing climate risks within service components are often unclear.

One of the strongest findings of the interview process is the affirmation that engagement between researchers and operations personnel assists in identifying risks and is a necessary component for successful climate change adaptation integration. This important relationship between climate researchers, military personnel and civilian natural resource managers that perform informational, monitoring and reporting tasks presents a strong opportunity for coproduction of science and a high level of ongoing engagement. The need for site specific scenario based products and tools that can be readily used by existing as well as new military and natural resource personnel also highlights the need for continued interaction between climate researchers and military personnel at the installation level. A perfect example of this need for sustained engagement was identified during a debriefing session in which RC2232 researchers met to share findings with NBC. Over the course of the debriefing, and as scenarios and models were presented, the natural resource liaison responsible for various monitoring and reporting on fire and vegetation noted that he was trained as a wildlife biologist and could benefit immensely from being able to work with the interdisciplinary team to advance his limited understanding of fire-flood-vegetation regimes.

Steps forward could therefore include cooperative agreements to involve researchers and installation personnel in both research and education efforts on an ongoing basis. Specifically, working with a team to identify both short-term and longer-term science-based adaptation options that military personnel and natural resource liaisons can incorporate in order to manage risks is essential, as is making it clear that there are also costs associated with “doing nothing” in the light of current climate trends and future climate change projections. The need for these types

of interdisciplinary partnerships that are well poised to tailor climate change adaptation strategies for managing climate risk has been well documented in various disciplines over the last decade (Grygoruk and Rannow 2017; Walker et al. 2015; Bostrum et al.; Wood et al. 2012; Moser, 2009; Frumkin and McMichael 2008). Connecting innovative scholarly work to the existing expertise already in place at the DoD could improve relations between researchers and military personnel and result in significant risk reduction.

4.5.3. Leadership, hierarchy, and partnerships

Not surprisingly, the commanding officer in an installation strongly influences the priorities and operations of an installation. However, based on our engagement with military personnel in the four pilot cases and our interview results, it is clear that success in implementation of adaptive action is a combination of "top-down" directives and "on-the-ground" interest/concern/capacity related to climate risks. During our workshops and debriefings at Naval Base Coronado and Fort Huachuca there was considerable concern and interest within the lower echelons (especially operational personnel), but also notable disconnects between various levels of management. In order to function well as partners in a military environment, academics need to have a basic understanding of the military hierarchy of decision making and reporting.

Another important point made in the interviews is that many adaptive actions are already underway at installations, whether or not they are formally labelled as "climate adaptation." Respondents in all of the interviews stressed that climate change adaptation *is* measurably taking place at various scales within the DoD, but such efforts may not be fully recognized due to security protocols that limit discussions or the ways in which researchers tend to frame the concept of climate change adaptation. Academics and scholars use one set of language to describe adaptation and measure success, while the military uses other terminology and metrics that are not commonplace in the academic community. Partnerships that allow for better communication and development of mutual understanding of language, as well as opportunities to collaboratively assess the effectiveness of adaptive actions would therefore be helpful, as would cross training workshops and ongoing briefings. In other words, developing a common language that is respectful of the military decision context and command structure is an indispensable tool for researchers. Excerpts from the interviews where this was evidenced include:

> *"Most of us know that climate change is a big factor and it's something we need to consider but it is a matter of prioritizing - policy is set and then translated through different echelons – and not everyone has the authority to do much beyond translate the memo that was just translated from a superior that just received a brief that was handed to him after being translated from up above - and many of your guys on the ground are trained on what to do and what to do when basis– they do their job, they do it well, and it may never concern them as to why they are doing something – they just comply."*

4.5.4. Discussion

Our ultimate goal was to understand which institutions and incentives are necessary to increase the likelihood of DoD success at embedding climate change considerations in standard operating

procedures and to elucidate the hurdles that future research endeavors must acknowledge when exploring pathways for mainstreaming climate change adaptation. Based on the series of interviews conducted by the UA team as well as the pilot case studies and workshops, the greatest barrier to streamlining climate change adaptation training is cost, followed by the frequent transition of command and responsibilities linked to various roles of leadership in the command structure. Relevance and prioritization of climate change adaptation relative to other issues that are perceived as more immediate, as well as measurable utility of adaptation efforts were also consistently stressed as significant barriers.

A very clear theme from the interviews is that the lack of dedicated DoD funds specifically earmarked for adapting to climate change is making it difficult to leverage or gain traction for adaptation initiatives beyond existing federal mandates such as the endangered species and clean water acts. Several respondents suggested “identifying adjacent landowners and security cleared contractors that already have a rapport with the DoD and the service personnel at the installation as a way to leverage greater funding and asking who owns and manages the land that is used by the installation and to what degree are stakeholders surrounding those installations impacted.” Similarly several respondents added that “climate scientists may be able to support their efforts by working in tandem with economists and “on base” natural resource personnel to identify actual dollar costs of “not acting” to create line items that align well with DoD “requirements based budgets.” Further development of decision support tools and training in the context of climate change may also assist base commanders interested in championing such efforts in that it may provide “do-able” and cost effective pathways and communication strategies up the chain of command. Being a partner with a federally funded science program such as a NOAA Regional Integrated Sciences and Assessment (RISA) may also be an avenue through which military personnel education and training could be provided.

In addition to the need for expanded climate change adaptation tools and training, the need for new ways to visualize data in order to illustrate and translate the risks and the solutions – including the need for infographics and factsheets - was repeated in several responses. Respondents emphasized that “DoD is not a research organization” – and that “reactionary measures” are a trusted approach… so “partnerships are valued if efficiency and benefits can be measured.” Another interviewee added that

> *“High level climate science is coming to the forefront at many installations particularly as installations begin to island themselves in resources based issues such as water and energy – however the policies and funds to carry these towards standardization is a long process.”*

In terms of real-world military timelines, it was stated poignantly during an interview that

> *“10 years is 5 commanders away - meaning it’s the 5th or 6th Commander down the line that will have to tackle the problems.*”

As echoed during our ongoing RC-2232 workshops and debriefings as part of the larger UA SERDP project - developing training tools delivered at low or no cost to the installation (e.g. funded by a dedicated DoD climate change budget) would be welcomed. If possible, such activities should focus on enhancing and improving the knowledge base and role of natural

resource personnel who tend to have longer tenures on base, as well as key service component personnel who inform and debrief base commander. This approach could be a viable solution that harnesses the expertise of university researchers as collaborators, maintains the relevance of climate change as a risk multiplier and maintains a partnership that demonstrates measureable impacts. Partnering of researchers and natural resources personnel also creates a trusted and credible science and know-how driven relationship that may be leaned upon as new commanders transition to an installation. These types of partnerships could assist in identifying what is already being done, such as hazmat training, which could incorporate climate change issues such as increasing dust and other air quality issues that may interfere with the health of personnel, training exercises and equipment functionality. Our findings also pair well with those of Chan et al. (2012) and Weaver and colleagues (2013) in that our site specific case studies support the inclusion of consideration of ecosystem services such as erosion and flood control, carbon storage and climate regulation, though of course this must be in the context of specific needs and conditions of individual installations.

Multiple urgent climate-related issues exist, and opportunities, time and funding for specific climate change adaptation training are scarce. Establishing an advisory team of experts, natural research managers, and the DoD decision makers that can provide advice to multiple facilities in a given region may be a low-cost approach that addresses the military's need for a scaled protocol and clear options. Education and training at certain echelons and intervals of promotion within the ranks were also mentioned as potential entry points for transferring knowledge but efforts to insert climate change must be brief, meaningful and offer a measurable return on investment. In a review of the need for more robust education in the U.S. Army, Park (2016) noted that there should be an emphasis on critical thinking centered on issues linked to global environmental complexities and higher consideration of academic performance in command placement. In order to produce leadership with skill sets that holistically acknowledge climate change as a threat multiplier as well as a range of tools to address it, it will be necessary to embed understanding of mitigation and adaptation at various scales within existing military training.

4.6. Learning from international best practices for decision-making in the face of climate uncertainties

4.6.1. Background

The scope of this research was developed with the University of Arizona in the White Paper to Strategic Environmental Research and Development Program (SERDP) dated October 8 2015, approved by the SERDP program manager on October 23 2015. The White Paper outlined a set of integrated activities and investigations that address three central project goals:

I. Working within the DoD culture to mainstream climate change adaptation into decision-making processes and institutional structures;
II. Exploring climate change decision-support strategies that are resilient in light of uncertainties; and
III. Developing climate services for moving research to applications.

To meet these goals, Acclimatise focused on review of literature and interviewees to ascertain

best practices for decision-making in the face of climate uncertainty. Examples from international defense forces and well as other non-defense sectors were identified to further inform SERDP of additional approaches worthy of significant consideration. A principal finding is that if mission readiness is key, then climate risk management should be reframed in terms of capabilities not installations. Rather than focusing climate risk assessments on an asset by asset basis, our research demonstrates that there are many opportunities to refocus on risks to mission readiness and capabilities.

4.6.2. Best practices from foreign defense forces

The literature review in this section covers international defense organizations, focusing on evidence from the UK and Australia where noted organizational-level advances have been made in recent years.

In vulnerable regions such as the Asia-Pacific, in which over half of the world's natural disasters occur, it is likely the Australian Defense Force (ADF) will be called upon more frequently to deliver humanitarian assistance. A changing climate is also likely to affect critical military infrastructure. Sea level rise and changes in magnitude and frequency of extreme weather pose a risk to defense property such as naval and military bases (Barrie et al. 2015). The importance of these risks is emphasized by the fact that the ADF has the most extensive land property holding in Australia, comprising over 3 million hectares of land and 25,000 buildings with a value of approximately AUS$32 billion (Commonwealth of Australia 2015). The ADF will also face increased frequency and intensity of heatwaves, when coupled with overall rising temperatures, this will have health implications for ADF personnel working, training, and exercising under those conditions.

To examine how sea level rise will affect the ADF's bases, the military spent AUS$2 million on research (UNISDR ARISE n.d.). The research, carried out by international engineering and consulting firm AECOM (2016) in partnership with the United Nations Office of Disaster Risk Reduction, involved a two-stage process with high-level risk assessments and prioritizations of sites at higher risk, followed by detailed site assessments and the identification of adaptation options and was acknowledged it ADF's *2016 Defence White Paper* (Australian Government Department of Defence 2016a). The 2016 White Paper, which represents the ADF's overall vision and development goals for the next two decades, is fully costed and centered on mission capability:

> "*Beyond 2025, the Defence estate footprint will need to be further developed to accommodate our new high technology capabilities and* ***ensure that Defence is appropriately postured for future strategic requirements and the implications of climate change****. This will involve* ***developing new bases, wharves, airfields and training and weapons testing ranges****. It will also include* ***considering the long-term future of some Defence bases****, such as Garden Island in Sydney Harbour, as issues such as urban development, encroachment and capacity constraints within existing infrastructure affect the ADF's ability to safely and effectively execute its mission.*"

The investment plans have external private sector assurance, and the government has agreed to fund the goals set out in the paper “by increasing the Defence budget to two per cent of Australia’s Gross Domestic Product by 2020-21”. This will result in an investment of AUS$195 billion over ten years (Australian Government Department of Defence 2016a). The accompanying *2016 Defence Integrated Investment Program* is less explicit about climate change. With regards to infrastructure and defense estate, it states the need to adapt to “*changes in land use within communities around defence sites […] along with environmental pressures*”. Further on, the ADF base Garden Island in Sydney Harbour is said to “*need over $700 million in works over the next ten years to enable it to continue to support an expanded fleet*” and that “*Defence will undertake further work over the next few years to assess the longer-term feasibility of the Garden Island facility*”.[i] Given the content of ADF’s White Paper, it may be reasonable to expect that the feasibility assessment work and the potential $700 million investment will include some form of climate risk assessment and consideration of adaptation Australian Government Department of Defence 2016b). . However, further information on this is unavailable and this remains unconfirmed in the publicly available literature.

The Australian *National Climate Resilience and Adaptation Strategy 2015* also outlines climate actions taken by the ADF. Amongst some mitigation studies and measures, ADF is undertaking a study that will determine how climate impacts will affect training areas. To illustrate even more concrete measures, the Royal Australian Navy Base HMAS Sterling on Garden Island, Western Australia (not to be confused with Garden Island in Sydney Harbour), has been diversifying its power and water resources since extreme heat, wind and wave events threatened the supply of both (Commonwealth of Australia 2015). Another ADF White Paper, *Force 2030*, published in 2009, largely dismissed climate change as a problem of the future; climate change, it seems, “had not yet entered the ADF consciousness” (Thomas 2012). Additionally, the *2010-14 Defence Environmental Plan* also treated climate change as a footnote. Given that those documents are only a few years old, there has clearly been an increase in the interest in climate change, with ADF starting the process of planning for its impacts, albeit with little specific information published on this activity.

In the United Kingdom, climate resilience is one of the top priorities of the government and defense as identified in the *UK National Security Strategy (NSS) 2010 A Strong Britain in an Age of Uncertainty* (HM Government 2010). The UK is vulnerable to a range of climate impacts and weather extremes. Severe winters, heatwaves, and flooding from rivers, the sea, storms, and gales are becoming more common with annual insured losses from such extreme events amounting to £1.5 billion (DEFRA 2012). In December 2015, Storm Desmond alone caused estimated flood losses of £662 million (Insurance Journal 2016). Additionally, as noted by the Foreign and Commonwealth Office (2012) the British Overseas Territories (BOT) are amongst the most vulnerable places on earth and are almost certain to experience severe climate change impacts, including sea level rise and changes in weather patterns. The UK Ministry of Defence (UK MoD) is the second largest landowner in the UK with an estate of 240,000 hectares. Out of this, 80,000 hectares are built estate, which includes offices, living accommodation, aircraft hangers and naval bases. 160,000 hectares are rural estate, which comprises mainly training areas and is often environmentally important (National Audit Office 2007). The UK MoD’s worldwide estate, which extends over the BOT and other countries, including Germany and Kenya (British

Army 2016), is valued by the National Audit Office (NAO) at £18 billion.

The need for more comprehensive planning has grown over the last decade. In 2006, a report by the NAO contained a *Defence Estate Strategy* in which delivering "*the adaptations and efficiencies necessary to address the predicted impacts of climate change*" was stated as a priority and would be measured by developing a strategic approach, prioritizing how climate change impacts were to be addressed. Two years later, in 2008, the UK Climate Change Act was passed. In it, the government recognized climate change adaptation as a priority. The legislation also required the UK government to assess current and future climate risks to the UK every five years (UK Government 2008) and to establish a National Adaptation Plan (NAP). In 2010, the MoD published its *Climate Change Delivery Plan*, which detailed the actions for both mitigating and adapting to climate change. The adaptation objective was to "*ensure the MoD has the capacity to operate in a changing climate, such that defence capability is not compromised and any potential benefits from the future climate are realised*" (UK MoD 2010). Apart from specific actions to integrate adaptation into policy and capability planning, the document contained targets and indicators for adapting the MoD estate. The overall target is defined as: ***"Increase resilience to the impacts of climate change*** *by completing a* ***risk assessment, develop, implement, monitor and review an action plan*** *to improve the estate's preparedness to the impacts of climate change. Thereafter, a system of continuous review will be required on an annual basis"* (ibid).

According to the UK MoD *Climate Change Delivery Plan*, all new estate projects (construction and refurbishment) have to be accompanied by sustainability appraisals and, when subject to a 2015 Defence Related Environmental Assessment Method (DREAM) or Building Research Establishment Environmental Assessment Methodology (BREEAM) assessment, must achieve an 'excellent' rating (see http://www.breeam.com). Additionally, the document underlines the importance of understanding climate risks to existing estate and using that knowledge to inform business continuity and resilience planning.

In order to achieve this, the MoD uses its Climate Impacts Risk Assessment Methodology (CIRAM). CIRAM, delivered in 2010, was developed by Acclimatise and has since been regularly updated by the MoD. CIRAM helps identify risks caused by current and future impacts of climate and weather extremes on the outputs of MoD establishments (UK MoD 2015). Furthermore, the method identifies actions to maintain and optimize operational capabilities. CIRAM identifies:

- existing vulnerabilities to weather related hazards;
- whether existing vulnerabilities are likely to change over time;
- any additional vulnerability likely to arise in the future;
- the likely direct and indirect impacts on defense output;
- actions and measures to build resilience into defense functions of the establishment; and
- any opportunities created by changes in climate.

The CIRAM assessment has four key stages, summarized in Figure 49, which include a risk assessment workshop and the production of a Climate Resilience Risk Register. The MoD's

Sustainability & Environmental Appraisal Tools Handbook offers detailed guidance on how to carry out a CIRAM assessment.

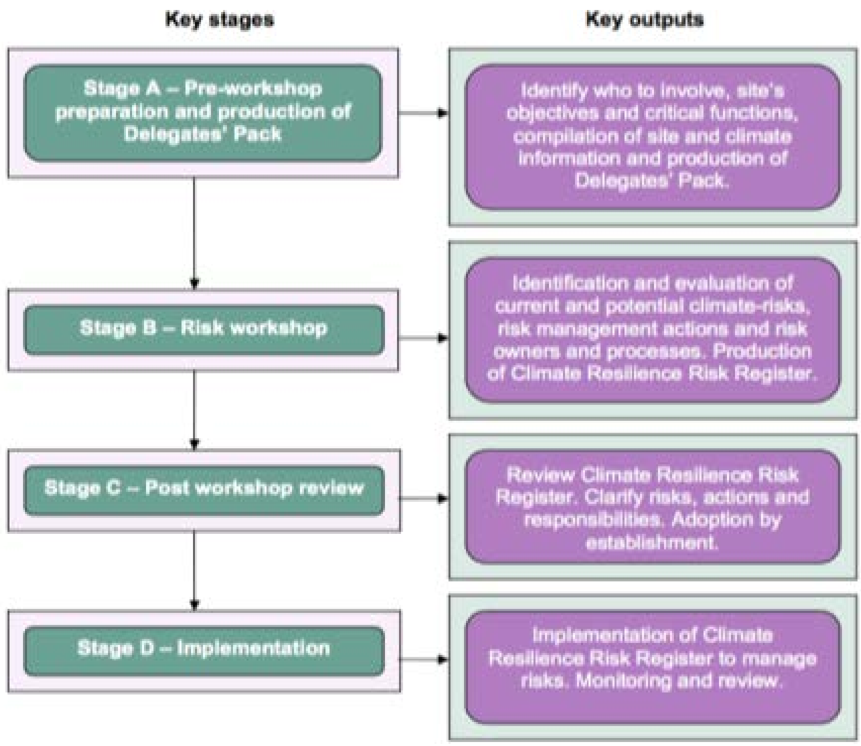


Figure 49: Key stages and outputs of the CIRAM assessment.

Stage A involves a desk study in which the objectives and operational functions of the establishment or installation in delivering the defense output are identified, details of the infrastructure, assets and utilities on the establishment are compiled, and historic and projected climatic information for the establishment are prepared. This information is then included in a delegate's pack for the workshop participants.

Stage B consists of organizing and delivering the risk assessment workshop, the output of which is a Climate Resilience Risk Register (CRRR). The workshop aims to identify:

- current and future risks to the operational capability of the site as a result of climate related hazards; and
- adaptation actions that would allow the site to become resilient to the effects of climatic events and therefore maintain operational capability, as well as identifying processes and risk action owners for delivery of actions.

In ***Stage C***, the completed CRRR is reviewed thoroughly, which gives the opportunity to clarify and/or identify new risks, and to clarify adaptation actions and responsibilities. This stage also includes the adoption of the CRRR by the establishment/ installation.

Finally, in ***Stage D***, the implementation process starts. Identified risks and actions are embedded

within the establishment's (installation's) processes. Site risk action owners are made aware of their assigned risks and how they are to be addressed in their processes and procedures. The risk action owners are also responsible for monitoring and evaluating the delivery of their actions. The Head of Establishment (HOE) is required to report annually to the Top Level Budget Climate Resilience Focal Point (TLB CRFP) regarding the delivery of adaptation actions. These regular reporting mechanisms ensure the adaptation actions are delivering the desired results.

The CIRAM process is embedded in a larger system of management measures. One such measure is partnership working. The MoD acknowledges the importance of involving different stakeholders in the adaptation process; this can be anyone from tenant farmers, contractors, water and energy suppliers to local authorities and resilience forums. The main motivation is to share knowledge and best practice, and to manage risks and impacts more successfully by working collectively (UK MoD 2012). Furthermore, resilience can be built by ensuring the estate's adaptation management is flexible, able to deal with uncertainties and also able to combine different risk responses (UK MoD 2016). Amongst other things, this entails having a thorough understanding of climate projections and latest scientific findings, and phasing adaptation actions by prioritizing them appropriately. Finally, actions also need to be embedded into existing establishment processes, e.g. into business community management, security management, estate management, and environmental management. More recently in November 2016, the UK MoD published its *Strategy for Defence Infrastructure 2015-2030*. The strategy has four main priorities: enabling defense outputs and capability, cost leadership, defense people and communities, and safe, secure, resilient, and compliant infrastructure. To achieve this, the strategy recognizes that developing and enabling sustainable and resilient infrastructure as a key component:

"A sustainable estate meets our users' needs whilst taking into account economic, environmental and social impacts, is adapted to future climates and is not reliant on constrained or depleting energy supplies and materials. Defence infrastructure is also a key enabler of resilience both for Defence and the wider UK. The use of our sustainability appraisal tools and the delivery of the Sustainable MoD, Business Resilience and Waste strategies will identify risks and opportunities drive coherence, innovative design and efficiencies and support informed decision making that aligns to our Strategic Objectives."

The UK's MoD has a solid climate adaptation strategy for its estate, the roots of which can be traced back a decade. With clear adaptation aims, a climate adaptation methodology, as well as climate change being officially recognized as a security threat, the MoD sets itself apart from many other countries where the military has either no climate change strategy for their estate or one that only looks at mitigation efforts (Danish Ministry of Defense 2016).

4.6.3. Best practices from non-defense entities

Given the general lack of published information, this literature review also called upon more readily available information from the public and private sectors, and in particular those organizations that share similar characteristics to DOD, namely a reliance on large, long-lived assets with large workforces and the need to manage natural resources carefully to maintain

operational continuity. Here we highlight examples from a) the Port Authority of New York & New Jersey, b) the State of California, and ports of San Francisco, Los Angeles and Humboldt Bay and c) the extractive mining, oil and gas sector.

The Port Authority of New York & New Jersey (PANYNJ), a bi-state agency that develops and operates trade and transportation infrastructure in New York and New Jersey, has many facilities similar or relevant to a defense agency: airports, marine terminals and ports, tunnels, bridges, rail transit systems, etc (Mills-Knapp et al. 2011). Figure 50 shows that most of the PANYNJ infrastructure is coastal and over half of its facilities are potentially vulnerable to the impacts of climate change. New York City has over 500 miles of coastline exposed to sea level rise. For New York and New Jersey, the IPCC's projections of climate impacts include increased precipitation, an increase in storm surges, both exacerbated by the coastal location, and also significant sea level rise (Romero-Lankao et al. 2014).

Figure 50. Vulnerable PANYNJ facilities (red dots)

In 2007, New York City released its *plaNYC – A Greener, Greater New York*, a document aimed at preparing the city for its rising population, strengthening its economy, mitigating, and adapting to climate change. In the document climate impacts such as sea level rise, increased storm frequency and intensity, and increased temperatures are mentioned as potential threats to New York City (City of New York 2007). The main adaptation focus of *plaNYC* was planning for disasters, more specifically, flood events, and tracking emerging climate change data and potential accompanying impacts Concrete actions included creating a strategic adaptation planning process, updating floodplain maps, and amending the building code. Five years later, after Hurricane Sandy, the City of New York released a resilience roadmap, *plaNYC - A Stronger, More Resilient New York*, which would be completely focused on resilience building and climate adaptation (City of New York 2013).

In 2011, PANYNJ recognized the importance of not just focusing on sustainable design that would help mitigate the impacts of climate change, but also looking at climate change adaptation and making their estate climate resilient. The inception of this project was based on different climate models and predictions, including the IPCC's, but also on a study by the University of Utrecht that stated New York City would likely experience sea level rise 20% higher than the IPCC global average estimate of 28cm by 2100 (Mills-Knapp et al. 2011). Using the adaptation-planning framework from the IPCC's *First Assessment Report* (IPCC 1990), PANYNJ started

developing different adaptation strategies for its estate. Climate change adaptation responses are categorized as either structural or operational (Mills-Knapp et al. 2011). Structural ones will usually include large, capital-intensive projects involving extensive planning, design or redesign. Operational ones, on the other hand, refer to changes that are more incremental; this includes enhanced maintenance, modification, or redesign. The potential strategies of structural or operational responses are categorized into protection, accommodation and retreat, with retreat being more of a last resort measure. PANYNJ determined that protecting and accommodating their estate were the options they would be focusing on (Table 17).

Table 17. Possible measures for the three adaptation strategies protect, accommodate, and retreat adapted from Mills-Knapp et al. 2011.

Protect	Accommodate	Retreat
- Barriers (permanent) - Barriers (temporary) - Coastal armoring - Coastal sand dunes, beach nourishment	- Pumps, sumps, catchments - Enhanced maintenance - Wetland protection, restoration - Underground storm water storage - Natural storm water management - Green roofs - Elevated buildings - Floating infrastructure - Waterway deepening/dredging	- Managed relocation

The measures in Table 17 were individually considered by PANYNJ, identifying their advantages and disadvantages, finding their synergies and potential conflicts with PANYNJ's sustainable design principles, assessing the relevance of each measure to PANYNJ, and backing them all up with case studies (e.g. for permanent barriers, the UK's Thames Barrier was taken as a case study). PANYNJ created a catalogue of valuable climate adaptation information for each measure by learning from best practice examples of adaptation strategies from others globally. This information was then evaluated to determine which adaptation strategies would make most sense for the affected estate, and researching practical measures to fulfil those strategies. Furthermore, PANYNJ also made a point of emphasizing the importance of monitoring and evaluation of the measures implemented.

In 2015, PANYNJ published *Design Guidelines for Climate Resilience* for its Engineering Department (PANYNJ 2015). This document takes into account the climate projections mentioned earlier (sea level rise, storm surge, precipitation) but also includes higher temperatures.[ii] As rising temperatures become more and more evident, it is considered important to account for them as they can affect various materials (seals, metal) and vegetation on the estate.[iii] This guideline also partly shows the Port Authority's monitoring and evaluation process of its own adaptation strategy. Overall, climate adaptation is well integrated into the operations and planning conducted by PANYNJ, with strong links to existing sustainable design principles, highlighting that beneficial synergies that can be attained when mitigation and adaptation are considered together (Figure 51). PANYNJ's monitoring process allows them to maintain flexibility to introduce new climate considerations (e.g. new climate science model outputs) in

their future plans during their review of their existing strategies and measures. Even though there is no direct mention of *plaNYC in their Design Guidelines for Climate Resilience*, it can be assumed that having that document, clear guidelines and actions taken by the City of New York can encourage an enabling effect to integrate adaptation into PANYNJ's planning procedures.

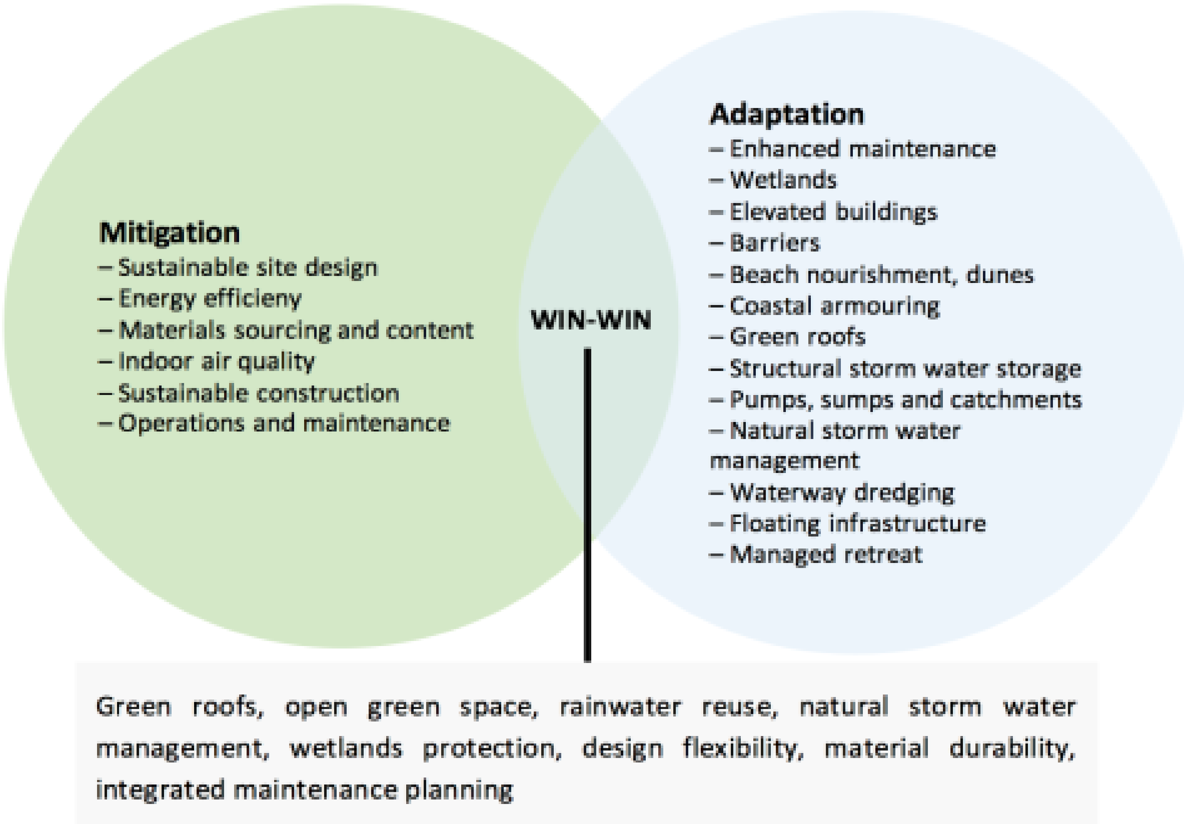


Figure 51. Mitigation and adaptation synergies for PANYNJ[iv]

The State of California and ports of San Francisco, Los Angeles and Humboldt Bay have faced similar challenges to PANYNJ. California's history of climate adaptation starts in 2005, when then-Governor Arnold Schwarzenegger issued Executive Order S-3-05, which not only called for specific emission reductions, but also for periodic updates about emerging understanding of climate science and climate impacts, and for adaptation efforts (Office of the Governor of the State of California 2005). Furthermore, the order states that future impact assessments include a "report on mitigation and adaptation plans to combat these impacts." The motivation behind the order, as stated in its text, was the fact that California is especially vulnerable to climate change impacts: increasing temperatures could greatly reduce the Sierra snowpack, a major water source for the state; increasing temperatures could also be harmful to human health, as air quality decreases, and heat stress and respiratory issues increase. Moreover, the 1,100 miles of California's coastline are threatened by sea level rise and threats to agriculture due to water stress and the distribution of pests and pathogens are significant. Soon after, a white paper was released that examined California's opportunities and constraints for managing the impacts of climate change (California Climate Change Center 2006). In 2008, Gov. Schwarzenegger issued another Executive Order, S-13-08, which would provide a clear direction for California's first state-wide adaptation plan (Office of the Governor of the State of California 2008).

Finally, 2009 saw the publication of California's climate adaptation strategy. In it, impacts projected in Executive Order S-3-05 were said to already have been observed, these included sea level rise, increasing temperatures, and increasing water scarcity (California Natural Resources Agency 2008). The document states that without adaptation action, tens of billions of dollars in direct costs could result per year, and trillions of dollars of assets could be exposed to collateral risks. Apart from covering impacts, risks, and strategies for a number of sectors, California's adaptation strategy followed a set of guiding principles that would help its organizational implementation:

- Use the *best available science* in identifying climate change risks and adaptation strategies.
- Understand that data continues to be collected and that knowledge about climate change is still evolving. As such, *an effective adaptation strategy is "living" and will itself be adapted* to account for new science.
- *Involve all relevant stakeholders* in identifying, reviewing, and refining the state's adaptation strategy.
- Establish and *retain strong partnerships* with federal, state, and local governments, tribes, private business and landowners, and non-governmental organizations to develop and implement adaptation strategy recommendations over time.
- Give priority to adaptation strategies that initiate, foster, and enhance existing efforts that improve *economic and social well-being*, *public safety and security*, *public health*, *environmental justice*, *species and habitat protection*, *and ecological function*.
- When possible, *give priority to adaptation strategies that modify and enhance existing policies* rather than solutions that require new funding and new staffing.
- Understand the need for *adaptation policies that are effective and flexible* enough for circumstances that may not yet be fully predictable.
- Ensure that climate change adaptation *strategies are coordinated* with the California Air Resources Board's AB 32 Scoping Plan process when appropriate, as well as with other local, state, national and international efforts to reduce GHG emissions.

During this time, when California as a state was setting policies in place to deal with the impacts of climate change, a number of other Californian authorities, such as local and regional agencies, started looking at how their communities and assets would be impacted by climate change, and how they could adapt to reduce the resulting risks. In 2008, the City of Los Angeles started researching adaptation planning. This included a climate change simulation for Greater L.A. commissioned by the Los Angeles Regional Collaborative for Climate Action and Sustainability (LARC) (Grifman et al. 2013). The simulations, done by UCLA, would help the city understand regionally specific impacts and plan for them. Amongst other issues, sea level rise was identified as a potentially harmful climate impact, especially given L.A.'s critical infrastructure along the coast which includes power generation facilities and wastewater treatment plants.[v] The city's port is one of the busiest in the world with 40% of all the country's imports coming through the Ports of Los Angeles and Long Beach (ibid). Having recognized the risk the city's coastal zones were under, the City of Los Angeles had a sea level rise vulnerability study prepared which resulted in an extensive adaptation strategy matrix, which would help plan and prioritize adaptation actions to reduce the city's vulnerability to sea level rise.

The 2007 management plan for Humboldt Bay, the second largest enclosed bay in California and also containing the Port of Humboldt Bay, included amongst many other policies one that stated: "*Identify needs for potential shoreline improvements necessary to accommodate bay water surface elevation changes, including potential effects of climate change.*" The State Coastal Conservancy had a report prepared for Humboldt Bay between 2010 and 2013. This report consisted of a shoreline inventory, mapping, and sea level rise vulnerability assessment and was the main component of phase 1 of the Humboldt Bay Sea Level Rise Adaptation Planning Project (Humboldt Bay Harbor District 2016).[vi] In phase 2, a report including hydrodynamic modelling and inundation vulnerability mapping, highlighting projected sea level rise impacts on Humboldt Bay, would inform the planning of relevant adaptation actions (Northern Hydrology and Engineering 2015). Recently, the Port of San Francisco also published its 2016-2021 Strategy Plan. As part of it, the Port seeks to work with the City of San Francisco in order to develop a resilience and adaptation strategy to support the necessary repairs to the Port's seawall, which serves as a protection against flood risk and sea level rise (Port of San Francisco 2016). The Port also aims to participate in local and state regulatory rule-making related to climate adaptation.

Across the extractives sector (i.e. mining and oil and gas), companies are exposed to climate risks that are also representative of key challenges faced by military installations. The reasons for this include:

- reliance on long-lived and capital-intensive assets;
- operations in regions that are highly vulnerable to climate extremes and climate change, including coastal environments;
- extensive product transportation networks which rely on deep and complex supply chains, both of which make operations vulnerable to disruption;
- dependency on 'beyond the fence line' stakeholders for the provision of municipal infrastructure, civilian products and services, the management of lands and other natural

resources (e.g. water supplies), which can be undermined by the effects of a changing climate; and

- management of environmental permitting arrangements.

As a result, extractives are particularly at risk from economic losses, damage to reputation, workforce health and safety concerns, legal and regulatory challenges. Moreover, they are typically and inexorably linked, and reliant on, other infrastructure and service providers, as well as others managing land use planning in neighboring or shared lands. The extractives industry as a whole is currently undergoing a process of integrating climate change risk management into existing business processes. With a few exceptions, the sharing of practical examples is limited given the necessary commercial pressures faced by private operators. However, there are a number of recurring best practice 'themes' that are common when companies implement such changes. One such example is that climate resilience actions are mainstreamed into existing asset/ project lifecycle processes. This reflects the reality that climate change risks do not usually create 'new' risks rather influence the likelihood and magnitude of consequence of existing risks. The co-benefit of this mainstreaming approach is that it increases the uptake of new approaches into existing governance structures and procedures. Figure 52 shows example 'hooks' into which climate risk management procedures could be integrated into a typical asset lifecycle.

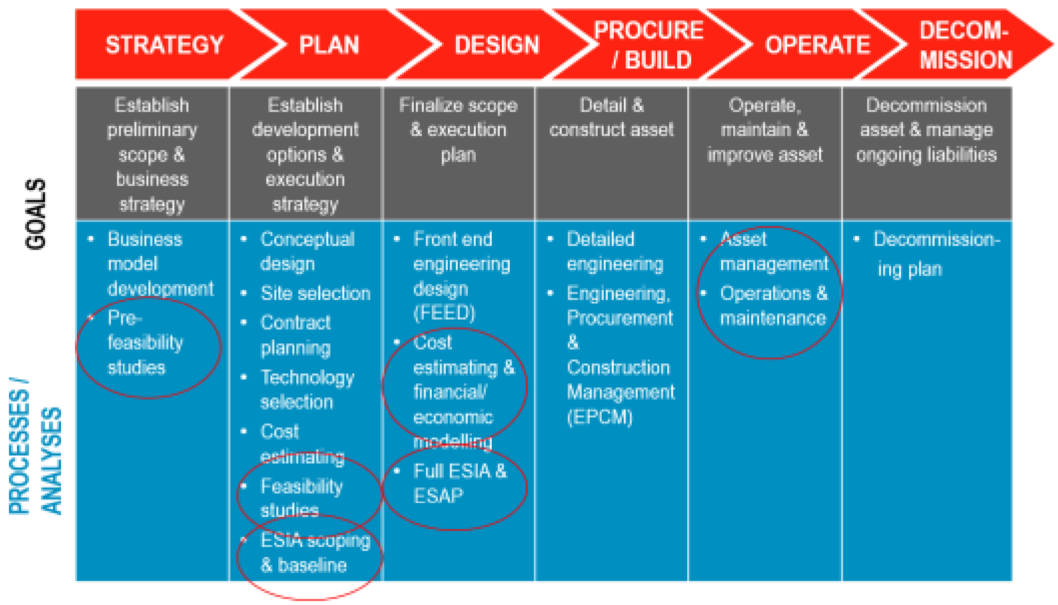


Figure 52. Example 'hooks' into which climate risk management procedures could be integrated into a typical asset lifecycle.

In support of mainstreaming activities, many extractive companies are developing climate risk assessment and management frameworks as shown in Figure 53, based around eight stages, from identifying objectives through assessing risks to choosing solutions and ultimately monitoring results, with the overall aim of identifying and developing robust resiliency decisions.

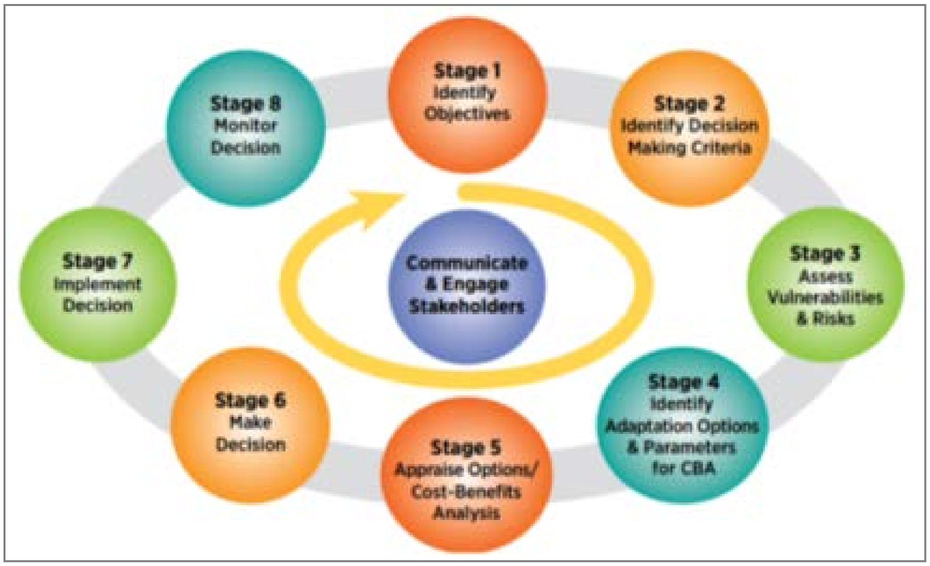


Figure 53. Eight-step framework for building climate resilience in energy systems Taken from HEAT 2010 Hands-On Energy Adaptation Toolkit, prepared by Acclimatise for ESMAP.

The ultimate goal of developing a specific climate risk management methodology approach is to identify ways to adapt the thresholds of assets to withstand the impacts of a changing climate. Figure 54 below demonstrates how adaptation actions give infrastructure extra headroom or coping capacity to withstand changing conditions, a concept adopted by a number of major international oil & gas companies.

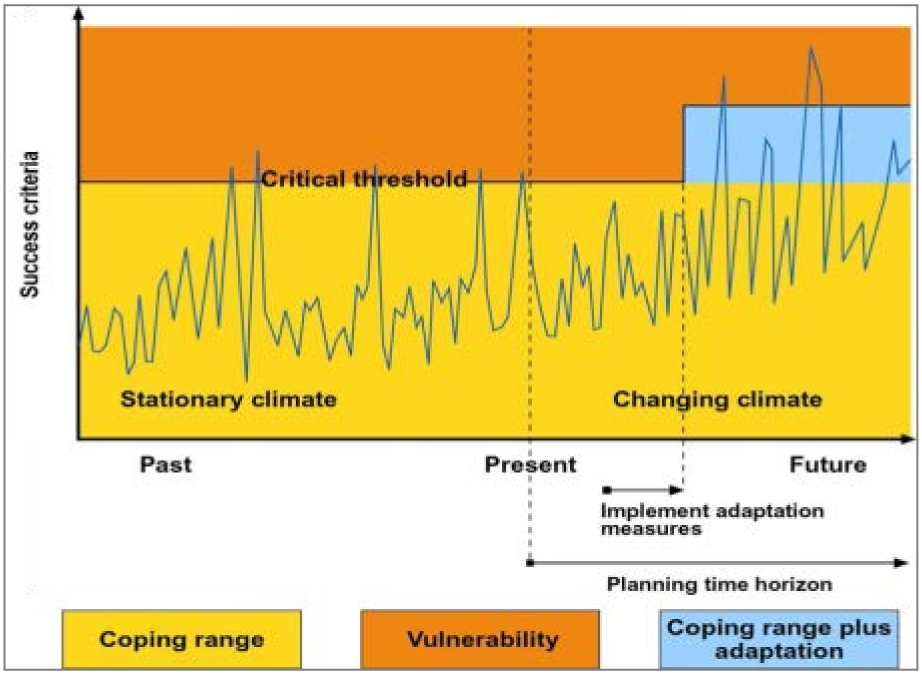


Figure 54.From Willows and Connell (2003). How adaptation increases the critical threshold or coping range of systems to withstand extreme weather and a changing climate.

Across the extractives industry there remains a tendency to focus on extreme climate-related events. There is, however, an emerging recognition of operational and maintenance risks driven by incremental changes in average conditions. Managing the risks associated with major events such as storms is important, and can garner significant attention and response, but these may have lower overall costs or revenue losses compared to the cumulative impact of smaller but more pervasive challenges, like efficiency losses due to higher temperatures. As such, leading extractive companies are starting to adopt a balanced focus on risks and opportunities from both incremental change and extreme events, cognizant of the different time horizons over which these events may occur. Figure 55 highlights this point, and poses the important question regarding the overall potential costs of climate change.

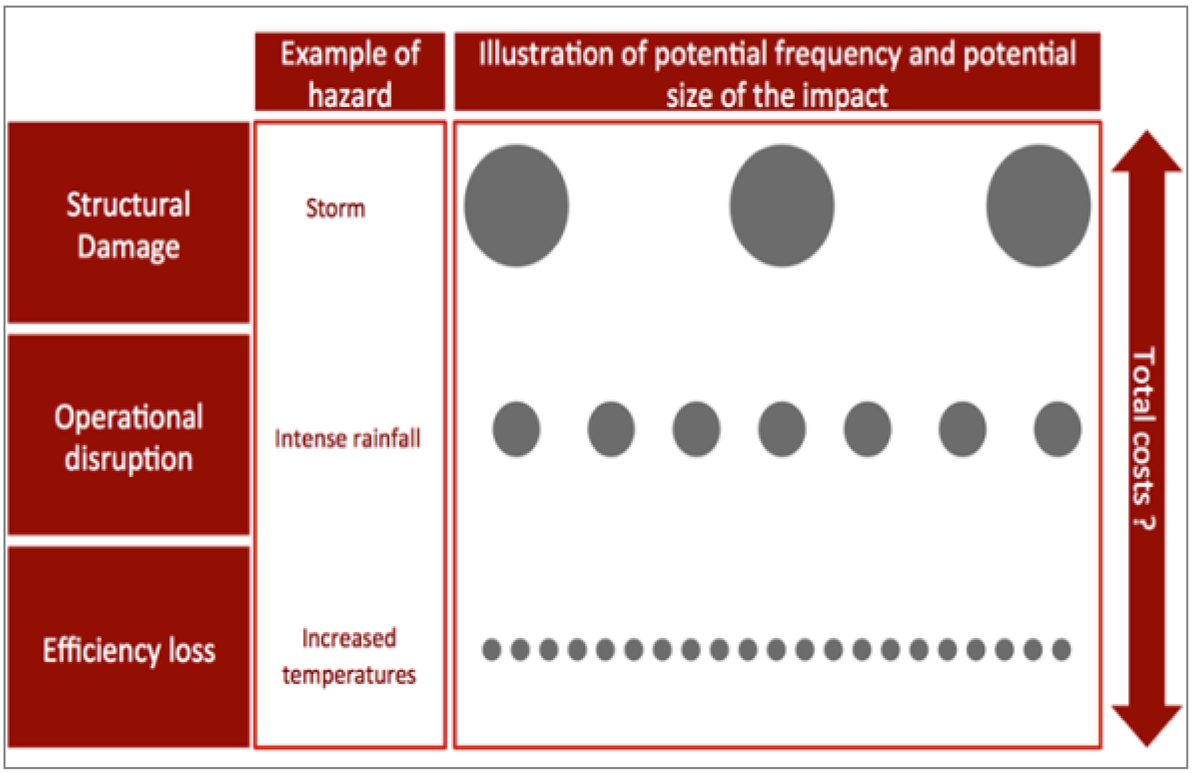


Figure55.The relative impact of large infrequent events compared to smaller but more frequent extremes

Another important factor to consider in planning adaptation action is in dealing with climate projection uncertainty. Many extractives companies are recognizing that there are limits to the assessment of climate impacts, as there are many uncertainties in future climate and socio-economic conditions. Bearing this challenge in mind, cutting edge developments in the industry currently focus on developing adaptation actions that deal with these inherent uncertainties, leading to assets and systems being designed to focus on resilience to today's events and tested for robustness against a range of plausible future scenarios. The key to this robustness lies in

developing solutions as ‘adaptation pathways’. Adaptation pathways embrace uncertainty, as they are flexible routes that allow changing efforts to build resilience in response to changing needs, information, and conditions. This approach is helpful given the ‘cascade of uncertainty’ associated with future climate change, as shown in Figure 56 below.

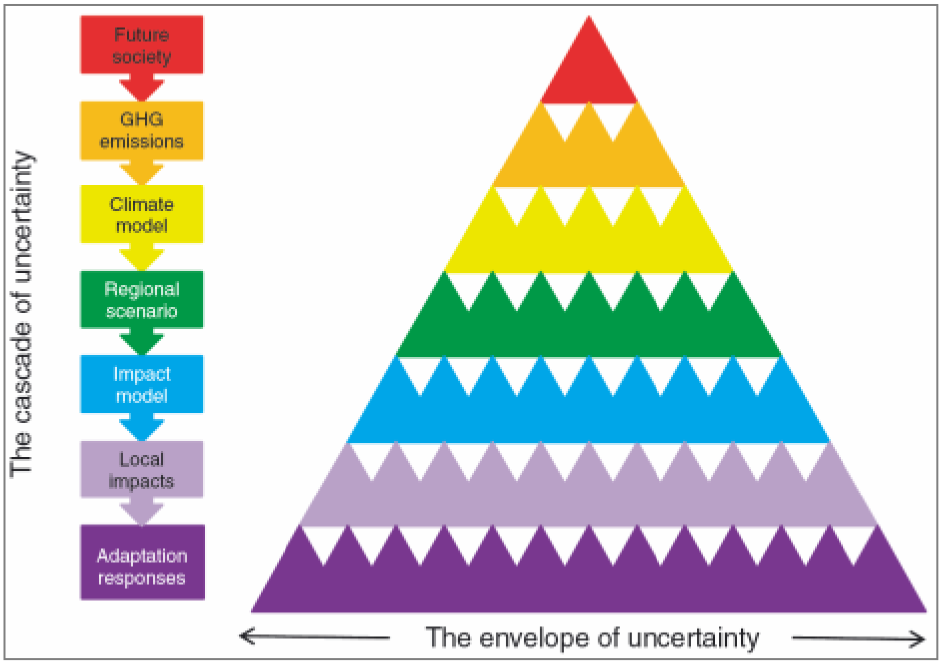


Figure 56. The cascade of uncertainty from Wilby and Desai (2010).

Extractives companies are becoming increasingly aware there are many ways to adapt to a changing climate, from ‘soft’ operational and informational adjustments to more costly ‘hard’ physical resilience measures. It is common for multi-criteria analysis and cost/benefit study to be used to identify and appraise sets of adaptation options, according to a selection of pre-defined criteria including costs downtime to benefits effectiveness, ease to implement and flexibility. The measurement of the effectiveness of adaptation actions can be considered to be an emerging area in the extractives sector. In many cases, the assessment of material climate risks is the limit of progress in the sector, although where examples of adaptation actions being completed do exist, it is often unclear what monitoring and evaluation procedures are applied, and if so, they are unlikely to be explicitly adaptation-outcome orientated. Moreover, the effectiveness of adaptation actions may need to be measured over the long-term, where success may not be ‘realized’ in less than decadal timeframes.

4.6.4. Attaining action through leadership and legislation

To achieve a better understanding of how different organizations, deal with climate resilience, Acclimatise undertook a series of interviews with stakeholders, from military personnel and infrastructure providers, to planners.

During an interview with a representative of the UK MoD, it was found that although approximately 90 installations across the UK had been assesses for climate risks, it is the responsibility of the personnel at each location to manage climate risks, the cross-cutting nature of the risks (e.g. impacts on security, business continuity, infrastructure, environmental protection etc.) means that there is no one person accountable. Given the medium to long-term nature of the risks, climate risks are afforded lower priority than immediate operational risks. Often where an individual has a personal interest, climate risks management is progressed. The interviewee went on to explain that climatic events are quite localized and their magnitude often not dramatic enough to be communicated or escalated within the MoD. Often risks are managed as they occur at the installation level, but they do not currently present a significant driver for change across the wider MoD hierarchy. The MoD is currently building up a body of evidence on costs and damages that have occurred at the installation level which can be used to enhance understanding of risks, reduce uncertainty and inform investment decisions going forward. This is typically undertaken by collating information from facilities management contractors (third-party private companies) that are mandated to collect this data. However, issues regarding mobilization of contracts means there has been a delay in collating this data. The UK Defence Infrastructure Organisation (DIO), responsible for managing the majority of the Defence estate, has gone through two major phases of organizational change over the past 5 years or so. This restructuring in the organization has meant maintaining climate resilience profile and the consideration of associated risks within the organization as a whole has been a challenge. The interviewee considers this a key barrier, and with a complex picture of contractors and MoD staff involved over a wide geographical region, they recognize that understanding the triggers when action should be taken to manage climate risks, coupled with a wide range of risk appetite across the organization, is a barrier to consistent agreement on when and where to act, and who is responsible for the actions identified.

The UK MoD interviewee also described how MoD risk assessments look across many aspects, and that typically there is no central owner for all risks, rather only risk owners for certain areas. For example, FM risks would be DIO, but there could be service risks that are owned by others. This distributed view of risk is a challenge that they are currently seeking to address. It is the "Head of Establishment" that is responsible for the installation, but they are not necessarily responsible for the management of all the risks at their installation. Monetary thresholds are often used to assist in determining the level of appraisal of sustainability and climate risks for capital works projects. Every new infrastructure capital project in the MoD must have a sustainability appraisal completed prior to construction so that risks identified can be integrated into the design of the facility or infrastructure. Capital projects over £75M have a higher tier of scrutiny applied than those worth less money. Ultimately, sanctioning of the project needs a) a sustainability assessment to have been completed, and b) a demonstration that all risks, including climate risks, have been addressed.

In a recent audit of the UK MoD's sustainability work completed by a management consulting firm, the interviewee explained that the results had shown that the MoD had clear direction at the highest level, with a small team of experts providing advice across the business as and when required. However, there is also a middle layer in the hierarchy of the organization where there is difficulty in operationalizing bottom-up data (such as information on climate risk management) into decision and investment planning. As such, with capital works projects, the interviewee

highlighted the MoD has achieved good mainstreaming of climate risk considerations through their sustainability appraisal process, supported by the MoD's investment approvals committee that is mandated to check on sustainability and climate resilience aspects. But for day to day maintenance and investment, there remains a lack of mainstreaming and good resilience outcomes. UK MoD's future developments in climate risk management, according to the interviewee, should be handled terms of looking beyond the installation level to start looking through the consideration of 'capability', for example viewing climate risks related to the 'capability' of air traffic control across multiple installations, which could relate to individual buildings on certain sites, technologies or procurement supply chains. In the current context of their CIRAM methodology, a focus on evaluating climate risks at the installation level provides only a single view of the installation where it is hard to see the criticality of that installation in the context of other locations, where there may be interdependencies. The interviewee highlighted that it is not necessarily the case that the FM contractors are aware of what are the most critical 'capabilities' at an installation due to a lack of visibility of the function of what is often a mix of differing units at an installation, and are therefore may be unable to fully prioritize climate impacts in a more systemic way based on criticality. At many MoD installations, external stakeholders' management is an integrated part of the ongoing management of the installations given the biodiversity, heritage, recreational value etc. on many installations (e.g. conservation, heritage and recreational organizations). However, the interviewee suggests that there is little external pressure from stakeholders regarding the need to manage climate risk assessments at installations. With statutory agencies (e.g. the UK's Environment Agency) there is dialogue with the MoD around the topic of climate resilience, and this this dialogue has informed action. The MoD does consider, however, that good stakeholder engagement and working positively with statutory bodies increases their understanding of Defence activities and allows military activities to be managed in a way that minimizes the impact of the environment and local communities.

Despite having climate-related procedures like CIRAM in place which focuses on risks at an establishment level. However, further thought is needed to understand how risks identified at a local level, multiply up to become strategic risks for the organization as a whole. Furthermore, the uncertainty of climate models in combination with the language used to convey climate change lead to additional difficulties in communicating risk. It is very important to speak in terms of impacts and subsequent costs, and frame the issue using tangible information. Finally, the interviewee described the "Strategic Asset Management", a process of evaluating which installations the MoD will retain and invest in, given the need to reduce the MoD's built estate by 30% over the next 20 years. In this evaluation, climate resilience and sustainability considerations will be part of the selection of the installations to be retained and invested in.

During another interview with a former British Royal Navy Officer having significant experience in the fields of climate change, and climate and energy security, the need to frame climate change issues in a military-operational language, rather than a "green" language, so they are more easily understood throughout the organization was heavily emphasized. For example, the increase in demand for energy in theatre was becoming a limiting factor for the MoD, and so describing energy reduction as key objective to maintain combat and support operations was much more effective that describing it in terms of 'sustainability' or other 'green' terms. As such, the challenge was to drive the shift from 'green' language to 'military operational' language within the MoD, and this was key in succeeding to address energy demand issues in the 2010 UK Strategic Defence Security Review. Like the UK MoD representative, this interviewee

also indicated that legislation was instrumental to the MoD starting to address climate change risks. As a governmental department, they were mandated to produce a climate change plan and started to look at wider implications of climate change, from structural ones to operational impediments, and security issues. In the operational military, there has been activity in broadening an initial focus on installations (i.e. infrastructure, and health and safety) to also focus on climate and geopolitical stability, UK national interests and security and, in terms of operational tasks such as what equipment and training personnel would be needed under a backdrop of operations in theatre. It was also suggested that organizational change can be very much personality-driven. As such, action is highly dependent on an individual's personal motivation. Given the pressure on resources in the MoD (be it staff, or budget), the focus still tends to lie on the most immediate problems. Furthermore, the time scales that define climate change can be problematic for the MoD context for several reasons. On the one hand, political horizons are short-term and often mandate the MoD's actions. On the other hand, future risks are often medium- and long-term, and uncertain. Uncertainty, however, is not a new concept to the MoD, and potentially there may be more certainty around the impacts of climate change than that of other geopolitical security threats.

Similar perspectives were also offered by a former Australian Defence Force officer with relevant experience in climate security issues. During the interview with the ADF Office, it was shared that climate action in the ADF is considered strongly to be dependent on political landscape and leadership. Significant barriers for the successful implementation of climate change adaptation actions within the ADF include the high turnover of appointments and changes in government as such transitions generally result in slow organizational change. This also complicates the issue of taking long-term risks and time horizons into account because the ADF needs to understand risks fully before taking action in order to withstand scrutiny. Overall, urgency seems to be a very important factor in taking meaningful action, e.g. in the case of large-scale disasters, the ADF responds quickly and efficiently, but the further time horizons extend into the future, the more difficult they become to address. According to the ADF office, there are three key factors that make a successful argument for climate change adaptation: addressing capability, reducing costs, and including mission readiness. On top of that, the interviewee mentioned that increasing the overall awareness within the ADF is a very important step. Championing this effort is the Defence Support Group, who regularly produce briefs and reports to raise awareness, as well as the Energy Group and the Estate & Infrastructure Group. The leadership of the ADF has been lacking in this regard, although this may well be connected to political sensitivity.

4.6.5. The role of tools

Our findings emphasize that tools alone - do not make an approach. The development of climate risk assessment tools can be an effective way to standardize and allow for inter- and intra-comparison of the magnitude and consequences of climate risks for military divisions. The development of the CIRAM process in the UK has enabled a portfolio-wide assessment of climate risks. However, too much emphasis on using specialized assessment tools without a clear mandate to develop adaptation options (and affect change) can create a 'box-ticking' attitude; the use of the specialist assessment tools by specialist departments is considered sufficient to address the risks by the organization or responsible department. Stakeholder engagement and collaborative working should be therefore enhanced. We posit that an integrated approach to

developing adaptation solutions with stakeholders builds trust, ownership and can ease efforts through shared working. There are useful examples from the NYC Mayor's Office where stakeholder engagement across a wide range of groups was a key success factor. However, in military terms, outreach with stakeholders is typically limited to cooperation with statutory agencies, for example in terms of land management, or in the context of compliance with permits. A broader reach in terms of stakeholder engagement may move from desirable to essential as climate-induced pressures affect stakeholders and competing users of scarce and shared resources, ultimately undermining the social license to operate. The military needs to look elsewhere for best practice as maturity (and capability) of climate risk management in the military is low internationally. The challenges facing the military to deal with climate risks at the installation level are common to other public and private sector organizations. As such, there is an opportunity for knowledge transfer and collaborative learning through exchanges with organizations that have already successfully mainstreamed climate risk considerations. Looking inward within the military sector and establishing knowledge sharing just between military organizations internationally is unlikely to reap significant rewards in terms of learning.

Cyber security weaknesses could equally affect open source tools and other sources of data. Much of the literature relating to climate change and the military is focused on global security issues. All participants of the interviews conducted for this report mentioned climate change as a driver for political and civil unrest. Noticeable by its absence in the literature, however, is mention of the cyber security risks relating to access and use of climate data and derived results. Military organizations such as those in the UK and Australia are relying on climate and natural hazard data derived by academic institutions, consultancies and open source portals. Open sharing of climate projection data by the Earth System Grid Federation (ESGF), for example, who use a system of geographically distributed peer nodes to host the premier collection of simulations and observational and reanalysis data for climate change research (including IPCC[vii] assessments), could become a target for cyber-sabotage. Interrupting services, obtaining user information, or worse manipulating climate projection data could undermine the ability to effectively evaluate risk. For example, sea level rise projections for a low-lying small island location could be manipulated to cause an under-estimation of the extent of future inundation risk, leaving the installation under protected against flood impacts. Moreover, analysis of climate risks can reveal potential areas of compromise to existing assets and installations, potentially providing information on weaknesses in security. With academic and consulting institutions often engaged in supporting climate risk assessments, the security of information held by these non-classified organizations may also be of concern.

4.6.6. Mainstreaming best practices

In our review of best practices from both the UK Ministry of Defense (MoD) and Australian Defense Force (ADF) a key factor in successful mainstreaming is that climate change must be communicated in military and operational language, not in terms of sustainability, environmental or other 'green' programs. One interviewee emphasized the importance of speaking in terms of impacts and subsequent costs, and framing climate risk using tangible information, and the second interviewee expressed it similarly, saying the issue should be framed using specific 'military-operational language'. There are, however, also very complex issues inherent to climate change, i.e. the uncertainty of models and projections, which need to be conveyed. It is important

for the military and its operations to understand its own risk tolerance. Working with different time horizons, and planning for different levels of uncertainty, i.e. making commitments to short-term, low-uncertainty projections, and monitoring long-term, higher-uncertainty ones, can make the issue more tangible and easier to work with.

Once mainstreamed, there is a need to make climate risk management resilient to political change. Political will to drive national interests in climate risk and adaptation can vary significantly between administrative terms. As such, finding ways to build consistency of practice and continual improvement in the medium- and long-term is key to the successful delivery of adaptation goals. The New York City Mayor's office for example has driven the permeation of climate risks management, building resilience and promoting sustainability within all its departments, including the clear distinction and distribution of roles that will deal with climate-related activities. Once these types of practices become the 'norm' or business as usual, they may then be more likely to withstand changes in political will and the wider political landscape. Similarly, legislation is crucial. Legally binding action on mainstreaming climate change across Government departments, executive agencies and organizations such as the military are crucial to drive change. Examples from the U.S. Executive Orders 13653/13677 and UK Climate Change Act 2008 are important drivers for change, including driving reform in other relevant policy areas and cross-departmental collaboration. For both the UK and Australian contexts, without strengthening legislative drivers (albeit absent in Australia at present), and independent monitoring and evaluation of outcomes, tangible climate resilience outcomes will be hard to achieve through piecemeal voluntary action on managing climate risks. Responsibility must also be mainstreamed into job descriptions, objectives and targets for promotion. Change in the UK MoD for example can often be very personality driven and thus be dependent on the motivation of individuals. As such, mainstreaming climate-related responsibilities into certain job roles and setting targets for promotion might help transition climate risk management into the day-to-day routine.

4.6.7. Discussion

Based on the evidence reviewed and expert elicitation, the following key points have emerged. Evidence from both literature and interviews conducted for this report clearly highlights that there remains significant progress to be made by all military organizations in dealing with climate change risks to installations, including those with relatively progressive policies and programs, such as the UK MoD. There are areas of good practice, however they tend to be related to 'easier' to achieve aspects of mainstreaming climate risk management, but even then, they exist in isolated pockets rather than as systemic practices. Key issues running through our evidence include challenges around political will and leadership regarding climate action, prioritization against other competing activities, and communication of the issue, risk ownership and difficulties in considering the longer-term view. These issues, however, are not unusual challenges to mainstreaming climate risk and more widely disaster risk management and lessons emerging from the literature and interviews conducted for this report share strong similarities to well established conditions for enabling action that include advocacy (internal and external), leadership commitment, policy and strategic framework, institutional capacity and the project management cycle. In terms of leadership our approach highlights the idea of "minding the gap" as a convenient metaphor for illustrating that leadership gap at various levels of hierarchy. There

is evidence that the "middle management" can be the hardest to reach. At the installation level, consideration of weather- and climate-related risks can be, in its simplest form, a function of observation of impacts driving action. For example, for an installation facing increasing wildfire risk, leadership in managing this increasing risk can be clearly linked to experience. Equally, top-down leadership on mandating the need for climate risk management can assist in setting overall organizational direction and imperatives, however, there is difficulty in operationalized bottom-up data on climate risks into policy and planning led by middle management. This "middle management" gap can represent an important barrier.

The normative development of climate risk management approaches in the military may not create a perfect fit. Although there have been studies in the UK, Australia, and the US aimed at looking at the long-term climate risks on installations (and particularly on sea level rise), much of the evidence gathered for this report suggests that weather- and climate-related risks are being managed as they materialize. As described by all three interviewees from the UK and Australia, the decision to act on a climate risk is typically driven by short term goals and urgency. The difficulty in successfully managing long-term climate risks, in the context of organizations that essentially operate through short- and medium-term planning and decision-making framework is a global problem; however there are areas of practice that may assist in overcoming this issue. One area of practice that may offer a level of compatibility with the shorter-term gearing inherent in the military may come from the principles of disaster risk reduction (DRR). The Sendai Framework on Disaster Risk Reduction (SFDRR)[viii] outlines a series of relevant priority areas that represent good practices, including investing in disaster risk reduction to build resilience (through structural and non-structural measures), as well as enhancing responses to extreme events and following the principal of "Build Back Better" in recovery, rehabilitation and reconstruction. An approach using a more short-term DRR view point also has the benefit of addressing existing climate-related risks and vulnerabilities, as well as potentially aligning more readily to the time horizon of budgets and strategic plans. Climate risk needs must certainly be expressed in terms of loss and damage related costs. This point also falls into the category of 'tangible information'. Collecting evidence of climate-related costs and damages that have occurred at the installation level can serve as hard evidence that climate risks are already an issue that needs to be dealt with. On the other hand, taking that data and combining it with future models and projections offers a way to estimate the cost of climate inaction, which can be a powerful tool for creating agency and action.

The establishment of technical climate change panels and connecting via outsourcing to contractors was also noted as effective means to solve problems. As in the example of New York City Mayor's Office, a climate change panel that provides authoritative and robust information tailored to the needs of the entity that set the panel up, can be a very valuable tool to solve climate-related problems, bringing together researchers from outside provides an independent and more objective look on climate risks. Additionally, there is an element of oversight and steering the panel to fill research gaps important to the organization. Furthermore, such a panel provides an opportunity for cross-learning and continuity; the latter might essentially be of great value for military organizations, which experience a high turnover of personnel. Finally, a climate change panel might also be beneficial with the aspects of 'credibility' or 'believability' of the data provided, coming back to the issue of data provenance as described above. Outsourcing contracts can also incorporate climate risk management objectives and serve as an

opportunity for insertion. The UK MoD for instance outsources its facilities management to third-party contractors. Contract terms of reference are an important vehicle for integrating climate risk management considerations, providing the opportunity to detail specific activities, including monitoring and evaluation tasks specifically aimed at gathering information on particular climate risk areas of concern. Reporting of these risks at the installation level can be achieved alongside other routine monitoring tasks, and provide an opportunity for bottom-up reporting to managers at both installation, regional and national levels. Aggregated data could also provide useful comparisons across installations in a given geographical region.

4.7. Transitioning Climate Change Research to Applications (R2A)

In the context of the UA-SERDP Cross-Project Workshop, most lessons learned were consistent with findings of previous research on connecting research to applications, (e.g., Dilling and Lemos, 2011; McNie 2013) though additional challenges and opportunities were identified. Our understanding of the DoD structure and culture, approached through multiple lines of investigation, illuminates the fact that there is still significant capacity building needed in order for climate related risks to be well-considered, let alone addressed. Beyond sheer capacity and "bandwidth" issues, other challenges to incorporation of climate-related information include lack of dedicated funding for climate issues, the rapid turnover of personnel at individual installations, the very short-term focus of most decision-making, the lack of horizontal integration across branches of the military and even between operations and mission activities on the same base..

4.7.1. Incentives and Opportunities

Despite these concerns, the DoD has many opportunities for enhancing the research to applications transition and promoting innovation. For example, the hierarchy and command structure can ensure adoption of new policies and technologies more quickly than other parts of U.S. society if a priority is established by leadership. In addition, DoD has very high credibility among a wide range of U.S. citizens, and is already perceived as leaders in the climate area, particularly due to the very visible statements about climate risk made in a series of quadrennial defense reports and by highest-order leadership in the Obama administration (cite National Geographic article?).

There are many kinds of incentives that influence decision-makers in civil society; these same motivations can also affect military leaders. Many businesses, local, regional and state governments, and non-governmental organizations already are motivated to use climate information to take action to minimize climate risks, especially the high costs of extreme events. Many are also motivated by the potential to maximize economic opportunity; advance their careers by showing leadership; be good citizens of their communities; and contribute to the protection of environmental systems and ecosystem services. The "command and control" aspect of DoD means that it is important to consider the findings of this project in the context of the official "incentives" provided by the upper end of the military hierarchy.
Our project was conducted during the Obama administration, which established through a series of executive actions that climate preparedness was a priority for every agency. These executive actions required Federal agencies to identify and prepare for climate-related threats. For example, in 2009, Executive Order 13514, *Federal Leadership in Environmental, Energy, and Economic Performance*, directed Federal agencies to develop Climate Change Adaptation Plans

to identify risks to their operations, missions, and programs from the effects of climate change. Federal agencies released their first Climate Change Adaptation Plans in February 2013. In June 2013, the President issued his Climate Action Plan, which established goals in three major areas (along with a long list of priority projects): managing climate related risks, managing greenhouse gas emissions, and establishing U.S. leadership in international climate programs. Priorities included working in partnership with communities across the US, protecting infrastructure, protecting the economy and natural resources, and use of sound science to manage climate change impacts. Then in November 2013, through Executive Order 13653, *Preparing the United States for the Impacts of Climate Change*, Federal agencies were directed to take actions to increase resilience, including modernizing Federal programs, managing land and waters, providing information, data, and tools, and updating agency adaptation plans.

Since 2014, agencies reported on their progress on an annual basis and their plans and progress have been reviewed by the Council on Environmental Quality. The March, 2015 Executive Order 13693, Planning for Federal Sustainability in the Next Decade, directed Federal agencies to further increase energy efficiency, improve environmental performance, and incorporate climate resilience into these efforts. In September 2016, a Presidential Memorandum: Climate Change and National Security established a framework for coordination and directed Federal agencies to take actions to ensure that climate change-related impacts are fully considered in the development of national security doctrine, policies, and plans.

In addition to these executive actions, the Secretary of Defense published Directive 4715.21 in January of 2016 on Climate Change Adaptation and Resilience, the preamble of which is repeated here:

"In accordance with the direction in Executive Order 13653, this issuance establishes policy and assigns responsibilities to provide the DoD with the resources necessary to assess and manage risks associated with the impacts of climate change. This involves deliberate preparation, close cooperation, and coordinated planning by the DoD to:

- Facilitate federal, State, local, tribal, private sector, and nonprofit sector efforts to improve climate preparedness and resilience, and to implement the 2014 DoD Climate Change Adaptation Roadmap.
- Help safeguard U.S. economy, infrastructure, environment, and natural resources.
- Provide for the continuity of DoD operations, services, and programs.

4.7.2. Assessing DoD Culture

Given all of this clear guidance from the Obama Administration that climate resilience was a priority and that use of sound science was critical to sound decision-making, our team initially anticipated that there would be significant interest across the installations we worked with to jointly explore new sources of climate information and tools that would be relevant to managing risk. Although there was wide recognition that these topics were a priority in a general way, it was actually quite difficult to find "points of entry" and significant interest in engagement with our team beyond the access that came from prior relationships between our researchers and base personnel. At Naval Base Coronado, we did have initial leadership support for our engagement, and this led to early access for our team; at Fort Huachuca, the access came through relationships with operations personnel with whom the team had previously interacted in the context of fire

management efforts. Across all bases, however, access and engagement was challenging – in some cases our on-base contacts changed, which led to a need to take multiple steps back for each step forward in engagement. It was hard to build and maintain the "trusted relationships" that we know from experience are a critical part of successful bridging between science and decision making in literally all contexts.

Our conclusions, based on multiple lines of evidence, are that although the central administration of DoD was strongly supportive of the concept of climate preparedness, even after eight years of the Obama Administration there were significant barriers to engagement between base personnel and researchers and less use of climate information to manage risk than might have been expected.

4.7.3 Co-Identified barriers to mainstreaming climate change adaptation

Among the barriers we co-identified were:

- It was hard to get focus within the military on activities that were not *perceived* as mission critical;
- Internal DoD culture in some cases resists change, including engagement with external researchers; there are multiple good reasons for this, but it is a barrier nevertheless;
- Maintaining continuity in research to operations initiatives that involve a "learning curve" is difficult when personnel (including commanders) rotate through installations very rapidly;
- Communications processes are not always ideal between civilian employees, contractors, and active military personnel;
- Useful and relevant training programs (designed explicitly for particular regions/risks/etc.) are largely not available to the personnel who may be most in need of climate-related "risk management" capacity building;;
- There is an extremely short time horizon for most decision processes that are "top of mind" for commanders; critical short-term priorities take precedence over issues that are viewed as longer-term risks

4.7.4 Informed opportunities for mainstreaming

The cross-project workshop informed our understanding for existing and new opportunities within the DoD to mainstream climate change adaptation. We identified pathways that are largely the inverse of the barriers, for example:

- Once the risks associated with climate are understood, it is easy to see that they can seriously affect mission-readiness, *and we observed this change of perception at all four installations;*
- DoD's culture is "can-do" – if there is clarity about expectations, the command structure can make things happen quickly. This was echoed in the interviews as well:

> "*I think across the board we are doing a great deal – it may not be labelled as adaptation or mitigation but it is happening – in some places it is out of necessity and in other places it is possible that the commander has*

access to a series of officers tasked with environmental reports that work in tandem with the natural resource folks. I can give the example of endangered species at Camp Pendleton, and water reuse at a few other places - and another example is the ceramic paint cooling effect that the energy management team out at Davis Monthan has in one of their hangers – it requires no evaporative cooling now which is of great value"

- Though there is a long learning curve for most people (both civilian and military) on how to deal with the uncertainties about climate risks, it is relatively easy to imagine how those who have learned these lessons could disseminate them through the military as they rotate from one location to another – spreading innovation horizontally across installations and military hierarchies.
- As the climate community itself becomes better at communication of risks and opportunities for "win-win" adaptation strategies, the issues of communication across different components of the military personnel should also get easier.
- Because there are multiple levels of training programs already within DoD, sharing useful approaches and tools, such as vulnerability assessment, scenario planning, establishment of baselines and metrics to measure progress, iterative risk management strategies, and conducting economic and environmental assessments of the co-benefits of adaptation strategies should not be especially difficult if there is sufficient support for such efforts. One such idea is incorporating the concept of managing climate risk and associated planning tools into professional military education.
- The short-term focus of many commanders (affected by the length of time of their own rotation in each place) can easily be translated into a longer term strategy that occurs in phases or through a regional, interdisciplinary team of experts if there is support from the central command for addressing these issues.
- Contractors and civilians often stay in place while the active military personnel move on – they can serve as a memory bank for the installation and encourage longer-term risk management practices

4.7.5 Discussion

Our results here are centered on collaboration, partnerships and capacity building. Effective risk management efforts need to incorporate a "systems" perspective, to ensure that a full range of vulnerabilities and adaptation options are evaluated. Therefore, adaptation and resilience efforts need to consider implications for the mission that extend beyond the boundaries of the installation. A good example of why this approach is necessary is fire management, since large scale wildfires in the West often affect entire landscapes and certainly do not respect ownership boundaries. Similarly water and endangered species issues tend to require large-scale integrated solutions that may require the engagement of multiple landowners and communities. Further, military installations are almost always tied directly to a range of places where civilians who work on the base live and where broad arrays of services are available for personnel. Transportation, energy and water supply, and communications systems, along with health care, education, and recreation facilities usually need to be evaluated to get an accurate picture of the kinds of potential effects of climate impacts. This implies the need for community partnerships to address these issues, and researchers can easily become part of such partnerships. Neighboring

landowners, communities and agencies represent an array of resources and potential solutions. This means that preparedness can include plans for collaboration to address a range of possible future scenarios. This also raises the issue of how to ensure good communications and long-term relationship building between the installation and community leaders and research institutions of various kinds so that both extreme events and incremental changes can be managed. There may be a need for joint training exercises, emergency preparedness plans, as well as scenario planning across multiple interest groups. In our experience, the capacity to do this kind of work well is generally lacking on DoD installations, though there are excellent examples such as *Camp Pendleton, Lejeune and Davis Monthan Air Force Base.* Our team noted that there is a real opportunity for DoD to encourage regional coordination within branches of the military to address the training and capacity building aspects of managing climate risks. There are also many opportunities to ensure that DoD leadership is aware of existing internal resources such as the 14th Weather Squadron, which provides weather and some climate-related support to other components of DoD. Further, many existing federal science networks and universities regularly provide climate science support to decision-makers, and DoD could make substantially more use of these resources to bolster the existing capacity.

5. Conclusions and Implications

Department of Defense priorities and policies evolve in response to changes in global conditions as well as in response to changes in leadership in the US. DoD has been aware of and responding to climate-change related events, including in a humanitarian context, for much of the last century, but explicit consideration of anthropogenic climate change as a threat multiplier has become a serious focus only in the last ten years or so. Meanwhile, scientific understanding of current impacts and a range of future conditions has also been evolving rapidly, providing a wide array of new data and tools that can be used to help manage risk. It is in this context of expanded interest and opportunity for connecting science and decision-making at DoD that our project was conducted.

As an example of the rapid pace of change in the political arena, during the span of our project's trajectory President Obama presented his Climate Action Plan, with far-reaching implications in terms of managing emissions, managing climate risk, and providing leadership on climate; the Paris Climate Accord was signed by almost 200 countries; the DoD issued a directive that required all branches of the military to prepare climate adaptation plans; and then the Trump administration came into power with a decidedly different perspective about the importance of climate issues. It is very clear that providing a solid scientific foundation for DoD activities requires understanding the elements of human behavior that affect decisions – including the implications of changes in priorities from the top of the chain of command. Understanding how diffusion of innovation occurs, what the incentives are for civilians and active duty military to engage with researchers, how communities that are dependent on base personnel in multiple ways can engage in problem solving, etc., affects the outcomes. As our initial SERDP Program Manager, John Hall, noted in our cross-project workshop, the human dimensions of adaptation are at least as important as understanding the physical science of climate impacts, and have received far less attention to date.

Although directives from the top-down in the military are strongly affected by the political situation in Washington, we observed that at the installation level things don't change as much. The on-the-ground personnel at military installations have been dealing with many climate impacts, including sea level rise, more intense forest fires, drought, and changes in habitat for years. Whether or not these challenges are officially recognized for their connections with a changing climate, the impacts are real and must be managed. Therefore, the view of the world from the "bottom-up" is quite different than the "top-down" view. That being said, the four facilities that we assessed were located in very different local political conditions, with Naval Base Coronado in California, which is very progressive on climate issues, and the other three in Arizona, where the neighboring communities are much more conservative. These influences do affect the willingness of the "on-the-ground" personnel to engage in climate-related topics both inside and outside of our study area. For example, the Naval Base in Norfolk, Virginia is actively dealing with the impacts of sea level rise today, and there is no real debate about the fact that climate-change is a serious threat to their mission.

Climate and weather-related risks, regardless of discourse and nomenclature, will always be present – and the scientific consensus about the cause of these risks is real. The use of the "best available science" is a major factor in mission-readiness for the DoD. However, the specifics of

how to connect this knowledge to day-to-day decision-making is very challenging, especially when internal conditions are changing rapidly. Our project involved multiple different approaches to engaging DoD in dialogue to help identify current and future risks as well as evaluating a range of adaptation strategies. In every case, we found that the bases could use additional assistance in learning how to use climate science and an array of social-science strategies to enhance risk analysis and mission readiness.

5.1 Assessing data and information needs

Our assessments of data and information needs, from multiple workshops, interviews, participant observation, and literature review show a variety of data and information needs and concerns, from personnel at Southwest installations, as well as other Department of Defense personnel. Personnel at each installation that we investigated mentioned needs for improved access to data, higher resolution data, model predictions and projections, and central or shared data repositories. Associated with these needs, personnel expressed the need for standardized model projections, for (sea level, vegetation, water, wildlife) process model projections as well as climate projections, and for predictions of severe events. Workshop and interview participants noted that climate and environmental information, including observations, projections, and risk and impact assessments—that are site-specific and that encompass multiple spatial scales (e.g., local to regional) are needed; they also mentioned a desire for scenario-based products and tools for risk assessment and strategy development. Interviewees also highlighted the need for improved means of visualizing data, in order to illustrate and translate climate-related risks and solutions; they also repeatedly mentioned ancillary information products, such as infographics and factsheets, to help concisely convey key points.

The aforementioned data, information, and decision tools needs are universal and similar needs have been mentioned in a variety of civil society climate decision-making needs assessments (e.g., Melillo et al. 2014; Vaughn and Dessai 2014; Bierbaum et al. 2013; Lemos and Rood 2010; Jacobs et al. 2009). On the positive side of the ledger, we have noted that data, projection, and plan-sharing partnerships will contribute to the capacity of DoD installations to make climate change planning more routine—a success element for addressing climate risks. However, our team found that the security requirements of installations, and the Department of Defense generally, may affect the use of open source and shared access data with non-DoD entities; concerns range from non-classified information exposing facility vulnerabilities to enemies, to cyber-security risks that range from service interruption and information compromise, to data manipulation that results in under- or over-estimation of risks.

5.2 Assessing risk

Overview

Our team used multiple climate change risk assessment methods and found them to be adequate for climate risk assessment, and for infusing climate time-scale thinking into adaptation planning to address future climate risks; these assessments were not without challenges, as described below. At Naval Base Coronado and the Barry M. Goldwater Ranges, we used a structured risk

assessment workshop process (Willows and Connell 2003), described in detail in our white paper on Risk Assessment Methodology (Sagarin et al. 2014). Through the risk assessment workshops, we were able to identify acceptable levels of risk to be avoided. At NBC, we followed up the workshop risk assessment with an expert-based semi-quantitative assessment, which integrated the highest priority risks identified at the workshop with a formal U.S. Navy protocol for risk and emergency management. We also conducted a more narrowly focused (so-called "Tier 2") climate change risk assessment dialogue at NBC, to examine prospects for detailed risk assessment related to wildfire—one of the high priority risks identified in the workshop. At Fort Huachuca, we used an ad hoc method of risk dialogue on a high priority climate impact topic, risk of wildland fire, identified through the U.S. Army Corps of Engineers Climate Adaptation Planning Charrette methodology (Hayden et al. 2013); the FTH risk dialogue process was similar to the Tier 2 process at NBC.

What worked and didn't with our climate change risk assessment process

At Naval Base Coronado, we demonstrated that a combination of (a) participatory risk assessment, in a workshop setting, supplemented by (b) formal semi-quantitative risk assessment, (c) sustained and co-developed research on more narrowly defined risks, along with (d) ongoing follow-up interactions has strong potential as an integrated process for risk assessment and adaptation planning. Grounding the discussion in a framework of linkages between imminent climate-related problems and chronic long-term climate change challenges is a critical element for a successful end-to-end process for embedding climate change thinking in DoD planning and activities. This imminent-chronic framing formed the basis for workshop discussions at NBC and BMGR, formal risk assessment at NBC, and Tier 2 narrowly-scoped research interactions NBC and FTH.

We only conducted formal, semi-quantitative, risk assessment at NBC, and found that linking the assessment to existing military guidance, such as an existing manual and protocols for short-term emergency management was essential to the success of the method. The formal risk assessment method is transparent and allows for easy explanation of cause-and-effect linkages between climate and risk; cause-and-effect framing, like imminent-chronic framing is an important aspect of the risk identification dialogue. In general, while the risk assessment process can be time consuming, (a) it allows for a high-level installation-wide assessment, (b) assessment results can identify functions and activities that will require additional or more intensive coordination, given projected climate changes, and (c) the process can be easily conveyed, through a train-the-trainer process, in order to build assessment capacity and capacity to incorporate climate time-scale (i.e., years to decades) factors to inform decisions.

Climate change risk assessment intrinsically requires a broad-based conversation, in order to (a) correctly identify linkages across mission-related activities—which can lead to identification of risks that may not have been apparent only through evaluation of isolated activities, (b) to ensure that non-climate factors, such as coordination with beyond the fence line entities, and integrity of third-party infrastructure (e.g., water supply, energy generation and distribution, and transportation structures) are not unintentionally excluded—thus, exposing the installation to risk, (c) and for making the risk well understood by personnel. Through our in-person risk assessments and through examination of international best practices, we found that participation

by “middle management” may be essential for the correct identification of risks, and for communication of risks across vertical levels in DoD hierarchy. Thus, commitment across levels of hierarchy is an important success element in climate change risk assessment.

Similarly, we identified additional key factors in correctly identifying and assessing climate change risks. The climate change risk assessment workshop identifies risks to the installation’s function and mission caused by physical changes in climate conditions. This high-level (i.e. at the installation-wide scale) assessment, based solely on a one-day workshop, is insufficient to identify the detailed risks, and the connections across all installation functions (e.g., training, operational, managerial, and financial) that only Tier 2 and 3 assessments can address. From our Tier 2 wildland fire assessments, we found that once we actually sat down with personnel and conducted multiple iterative dialogues—only then did they understand the magnitude and breadth of the climate related risks. Key factors associated with these Tier 2 assessments include: (a) having sufficient installation-based expertise to assess technical details (e.g., at NBC’s Camp Michael Monsoor, the lack of a fire ecologist meant greater reliance on outside expertise to assess and translate risks); (b) including higher-level officials, as we did at FTH, made the conversation more relevant to the commanding officers and gave us better insights into the capabilities of the installation to integrate and act upon climate risk information; (c) not surprisingly, quantifying place-specific climate change risk builds awareness of pervasive effects of climate and increases capacity to incorporate climate change adaptation into other planning and risk management processes. Without placing future risk into the context of current concerns, climate change messages appear to be too abstract for DOD personnel to devote their limited time, attention, and resources.

Building on the previous point about place-specific risk assessment, based on our interactions at the four installations, and our assessment of international and industry best practices for climate change risk assessment and adaptation planning, we note that the risk assessment process is probably most effective when there is a clear articulation of the connections between risk assessment and strategy implementation. Making this linkage, between the risk assessment phase and the adaptation strategy and implementation phase is the focus of many of our conclusions, below; however, we emphasize that climate services can play an important role in bridging this gap, through minimizing the transaction costs for risk assessment, and for outside expertise to help identify risks and strategies, which was noted in a follow-up conversation with personnel at NBC. Moreover, best practices suggest that the establishment of technical climate change panels, via outsourcing to public or private-sector contractors provides authoritative and robust information tailored to the needs of the entity (or DoD installation), and bringing together researchers from outside provides an independent and more objective look on climate risks. The lack of Tier 2, place-specific, risk assessment at BMGR, probably limited the effectiveness of our risk assessment there.

Challenges

As mentioned above, ensuring sufficiently broad representation and participation in climate change risk assessment can be a major challenge. Lacking broad representation undermines identification of risk, and exposes installations to undiscovered risks (i.e., being blindsided by exposure to risk), and to unintentional development of maladaptive strategies. Support for

climate change risk assessment is essential; the most effective means of garnering such support may be through risk-specific engagement and quantitative assessment (directly answering the question “Why should this matter to me?”), as we found in our Tier 2 engagements on wildfire.

For our risk assessment method to be thoroughly useful to installation-based decision makers, ongoing interaction and support is needed. We were able to adequately provide such support through our Tier 2 fire risk assessment and collaboration activities at NBC and FTH. To support an installation-wide climate change risk assessment we recommend improved coordination between installation personnel, research and monitoring collaborators, contractors, and beyond the fence line land and resource managers; lack of such coordination could lead to so-called maladaptive approaches—where actions taken in with respect to one mission-critical function, in isolation from other mission-critical functions, can lead to a decrease in the ability to maintain mission readiness in the face of climate change. Beyond the fence line collaboration was especially important in our work with BMGR, and clearly contributes to their successes at piecemeal climate adaptation measures.

Ensuring that assessment and understanding of climate change risk is communicated to appropriate levels in the DoD hierarchy, is critical to avoiding maladaptations and/or exposure to costly risks, because the risk assessment sat on the shelf. Our examination of international defense and heavy industry climate change risks and adaptation planning suggests that weather- and climate-related risks are being managed, piecemeal, in a reactive, rather than proactive manner. Decisions to act on a climate risk is typically driven by short term goals and urgency. One practice that may offer a level of compatibility with the shorter-term gearing inherent in the military may come from a disaster risk reduction approach. NBC is probably using this kind of approach to address coastal sea level rise risks, and then formalizing climate-related risk management into a master plan, whereby long-term planning can be linked to urgent, short-term needs.

Opportunities

Enhancing DoD climate services, whether through investment in internal capacity or through partnerships with existing climate services capacity in federal, state, and university entities, can minimize transaction costs for climate risk assessment. This can also be achieved through MOUs and partnerships with beyond the fence line agencies.

Direct engagement of staff in co-designing research experiments and risk assessment provides an opportunity for greater buy-in, and more thorough risk assessment. The iterative process used in the coproduction of knowledge with FTH personnel was informative to us as researchers and to the installation staff to understand the current state of climate modeling capabilities and limitations, and how to access critical climate risk information, and to perform sufficiently in-depth risk assessment that it connected to improved understanding of climate risks and how mitigation actions may or may not influence specific outcomes.

Because a thorough risk assessment approach prioritizes credibility and cost-efficiency, it is much more likely to gain traction with the decision-makers in situations where there are known and immediate risks (Eakin et al. 2009). In other words, it suggests to decision-makers that

adaptation efforts are best directed at issues for which the risks are fairly well understood, with sufficient weight of scientific evidence to justify action – or what we are calling the imminent-chronic connection. NBC offered an excellent idea for making this connection—by mainstreaming climate change risk assessment with infrastructure master planning activities.

5.3 Engaging personnel in discussions on climate change adaptation

We examined communication, a main aspect of discussion and collaboration on climate change adaptation planning, through multiple lenses. In this section, we discuss the mechanics of researcher-practitioner (or scientist-DoD personnel) communication needed to "get in the door" or get the climate change adaptation conversation started. Again, we draw upon resources from multiple workshops that we convened, interviews with DoD personnel, defense personnel in Europe, and personnel in public or private sector adaptation planning initiatives, our participant observations, and literature review. The first hurdle to initiating substantive discussions about adapting to climate change is developing a shared language for talking about climate science, risks, and adaptation. Most climate scientists use the specialized jargon of academic research or environmental issues (resilience, sustainability), whereas Department of Defense personnel and civilian defense contractors speak the language of operations, mission readiness, and security. Even skilled climate communicators may find it difficult to bridge this communication gap, without adequately preparing to frame scientific results and concerns in terms that are compelling to DoD personnel, and that address the priorities of installations and the DoD. The literature on stakeholder engagement suggests that some of these concerns may be addressed through a recursive and iterative process. However, that process and associated trust-building exercises require time and repeated meetings; DoD personnel may lack sufficient time, may lack continuity (due to relatively rapid turnover in assignments to particular installations), or may suffer from fatigue related to meetings with multiple research groups, contractors, and civil society liaisons. Moreover, we found that many climate-related concerns may already be part of installation planning—although they may be framed in terms of extreme weather or other concerns, but not *climate change*.

To prepare for initial interactions related to climate change, DoD and defense-related personnel recommend that researchers communicate climate change in terms of operational language. This includes a focus on impacts, costs (or costs avoided), and other tangible risk-based terminology. DoD colleagues at Naval Base Coronado recommended framing the conversation around security issues, such as energy independence, water resource and water quality sufficiency, and mission-readiness. Our conversations on routine defense procedures at installations and initiatives in other countries also suggest that infrastructure and encroachment planning are important points of departure for tangible conversations about climate change. Climate-change impacts can also be viewed as encroachments, and articulating the interdependencies between a facility and the surrounding community can help DoD personnel identify interests at the intersections of risk and opportunity. The Australia Defence Force mentions similar concerns with its Garden Island installation in Sydney Harbour, where issues such as urban development, encroachment and capacity constraints within existing infrastructure affect the ADF's ability to safely and effectively execute its mission. If training is part of the installation's mission, then framing *go/no go* training decisions, in the context of climate change, may also assist base commanders interested in championing adaptation and preparedness efforts; this type of

language, when coupled with concerns about cost effectiveness, may provide pathways to meet requirements based budgets that are sent to and approved by higher levels of command. In our discussions with personnel at Naval Base Coronado, we determined that NBC can mitigate the risks posed by a changing climate by introducing necessary adaptation measures (e.g. water harvesting) based on an improved understanding of *the relationship between asset performance and environmental conditions*. Similarly, if mission readiness is key, then climate risk management should be reframed in terms of *capabilities*, not installation-wide concerns. Rather than focusing climate risk assessments on an asset by asset basis, there is an opportunity to refocus on risks to mission readiness and capabilities. Our interviews with European defense personnel show that the UK Ministry of Defence is innovating by considering this reframing, as it enhances the view of risk at the systemic and/or operational level.

Another set of language- or perspective-based issues are focused on uncertainty and risk. Despite substantial uncertainties in many aspects of resource, environment, and infrastructure management (e.g., population projections, economics, etc.), we noted a challenge in convincing DoD managers to act on climate change in the face of uncertainty. One aspect of this issue is improving understanding of decision making under uncertainty—generally, and within the DoD context—and understanding managers' and installation decision-makers' risk perceptions (see below). One prospect for overcoming this challenge is to focus the climate change engagement discussion on issues that installation personnel can control and/or the condition of installation assets with respect to climate variability (e.g., drought or flood episodes) and in terms of the adaptive capacity of the installation and its neighbors. An approach to risk perception and risk management is to structure researcher-practitioner engagements in terms of working together to co-identify challenges and risks. Our risk assessment method (Willows and Connell 2003) begins with dialogue to ask installations and units to identify how key decisions are influenced by climate and weather, and therefore how these could be affected by climate change—an approach endorsed by participants in our SERDP cross-project workshop; workshop participants suggested that a follow up would be to then discuss how SERDP and its partners can provide actionable resilience options and guidelines. Moreover, our one-on-one interviews with DoD personnel suggest that engagement between researchers and operations personnel to identify risks is a necessary component for successfully integrating climate change adaptation into routine planning (i.e., "mainstreaming"). This important relationship between climate researchers, military personnel and civilian natural resource managers that perform informational, monitoring and reporting tasks presents a strong opportunity for coproduction of science and a high level of ongoing engagement.

In interviews and through participant observation in our work on modeling and planning for future wildland fire-related risk, we found that site-specific scenario based products and tools, that can be readily used by existing as well as new military and natural resource personnel, form the basis for substantive climate change conversations and the development of formal risk frameworks. In such cases, the model serves as a boundary object, or tangible point of departure, for conversations about current and plausible future climate-related risk. Demonstrating the capacity to provide science support through, for example, modeling helped garner interest in thinking about climate time scale (years to decades) issues, and models can serve as points of departure for training centered on enhancing and improving the knowledge base of civilian natural resource personnel, who tend to have longer tenures than enlisted personnel, at

installations. Yet, we need to acknowledge that tools alone do not constitute an approach to climate adaptation. The development of climate risk assessment tools can be an effective way to standardize and allow for inter- and intra-comparison of the magnitude and consequences of climate risks for military divisions. For example, the development of the CIRAM process in the UK has enabled a portfolio-wide assessment of climate risks. Too much emphasis on using specialized assessment tools without a clear mandate to develop adaptation options (and affect change) can create a ‘box-ticking’ attitude, whereby the use of the specialist assessment tools by specialist departments is considered sufficient to address the risks by the organization or responsible department.

One final, and critical, aspect of successfully framing conversations about climate change adaptation is what we’ve termed the “imminent threat-chronic threat” or “short-term vs. long-term” perspective issue. Basically, in DoD, as in industry, public planning, and other planning and management contexts, decisions and priorities are typically driven by short term goals and urgency. Imminent threats, such as the risk of wildland fires encroaching on installation lands and affecting training and infrastructure, provide a compelling point of entry to discuss the connections between immediate risk and long-term risk, and gain a firm footing in climate change conversations. Infrastructure managers and those working in the Arctic tend to be leaders in the space between imminent and chronic threats, because of the magnitude of observed changes, and the perceived imminent threat to operations and infrastructure investments. Moreover, bridging between imminent and chronic or long-term risks may help with finding the right fit for DoD planning horizons. We note that the discounting issue is a big problem: once you get beyond the 5-year budget horizon, the interest in solving longer-term problems diminishes. Most DoD departments are not focused on planning more than 5 years out, because there are few incentives to do so. Short-term budget and policy challenges truly define the issues that most DoD decision makers focus on (N.B.: we comment more on this issue, in a section on military culture and norms, below). Urgency and relevancy of climate change adaptation was also found to fall behind more immediate and pressing strategic, operational and budgetary concerns—a reminder that funding is a critical motivator in these conversations. Nonetheless, one area of practice that may offer a level of compatibility with the shorter-term time perspective inherent in the military may come from the principles of disaster risk reduction (DRR). The Sendai Framework on Disaster Risk Reduction (UNISDR, 2016) outlines a series of relevant priority areas that represent good practices, including investing in disaster risk reduction to build resilience (through structural and non-structural measures), as well as enhancing responses to extreme events and following the principal of “Build Back Better" in recovery, rehabilitation and reconstruction. An approach using a DRR short-term perspective also has the benefit of addressing existing climate-related risks and vulnerabilities, as well as potentially aligning more readily to the time horizon of budgets and strategic plans.

5.4 Communicating climate change information

Communicating climate change information, as noted in the discussion above about methods to successfully engage with DoD personnel and decision-makers, is partly an issue of identifying entry points of interest to the DoD, and framing the communication in language and temporal and spatial scales compatible with DoD concerns and decisions. Specific issues related to climate change communication with DoD personnel include awareness of potential challenges related to

climate change, skepticism regarding human-caused climate change, differences in nomenclature, aligning the temporal and spatial scales of climate change with those of installation priorities, communicating uncertainty, and reconciling inconsistencies in the array of data and information available to installation personnel and practitioners. The studies in this project led to the broad conclusion that the key factors in successfully communicating climate change science to military personnel and civilian contractors at installations are making climate change tangible, expressing it through compelling graphics, and conveying evidence and projections of climate changes as actionable challenges to mission readiness.

Making it tangible. The recommendations of installation personnel, workshop participants, and interviewees stress that making climate change tangible requires researchers to (a) link global phenomena and trends to local effects, (b) link short-term (imminent) and long-term (trend-driven or chronic) phenomena, and (c) relate the impacts or potential impacts of climate changes with costs or avoided costs to the installation, the security of personnel and the installation, and with ability to conduct the missions of the installation and service branch.

Making it linked. Our interactions with personnel at Naval Base Coronado and the two Barry M. Goldwater Ranges (East [Air Force], West [Marines]) demonstrated the efficacy of the first two points. Our risk assessment and workshop processes were rooted in the examination of mission success criteria, participant identification of observed weather and climate cause-and-local effect chains that make clear the potential effects of changes in the frequency or magnitude of climate changes, examination of critical infrastructure value, and evaluation of climate-threat likelihoods and consequences in light of installation response capabilities. This approach fostered down-to-earth climate risk discussions with installation personnel. For Naval Base Coronado, linking the aforementioned process and metrics with the Navy Installation Emergency Management Program Manual, also connected a short-term risk plan, implemented at installation-level, with future risks related to regional and global climate phenomena. At Fort Huachuca, where we did not implement the workshop process, and worked with natural resource management staff (based on priorities identified by the U.S. Army Corps of Engineers), we used the tangible risk of wildland fire, witnessed only a few years earlier in areas adjacent to the Fort, and made connections by articulating the science associated with imminent risk, and providing tools and a process for assessing current and future climate-related risks. The ability to respond, with scientific information and decision tools, and to communicate in operational language familiar to Fort Huachuca natural resources personnel, proved be the most important communication factor.

Making sense of dollars. Participants in our cross-project workshop noted that documentation of the costs of past weather and climate-related damages or delays, and estimates of future costs of climate-related impacts, will enable the military to talk more freely about and respond more quickly to climate-related risks. This point was backed up in our interviews with military personnel in the UK, a country with a Ministry of Defence climate adaptation plan. Collecting evidence of climate-related costs and damages that have occurred at the installation level, can serve as hard evidence that climate risks are already an issue that needs to be dealt with. In addition, taking that data and combining it with future models and projections offers a way to estimate the cost of climate inaction, which can be a powerful tool for motivating action.

***Making it graphic*.** Interviews with a variety of DoD personnel pointed out that visualization of climate change data and information will go a long way towards translating climate-related factors, making associated risks visceral, and prompting thoughts and discussions with respect to solutions. In particular, infrastructure planners would benefit from visualization of phenomena, such as sea level rise, in order to better envision the vulnerability of coastal infrastructure and potential options for mitigating associated risks. The work of Stephen Sheppard and colleagues (University of British Columbia; e.g., Sheppard et al. 2011; 2013) provides examples of enhanced visualization of coastal and interior landscape changes at the nexus of the built environment.

***Making it actionable*.** Synthesis of remarks from workshops and interviews with personnel at Southwest installations and other DoD units highlights the need for communicating the connection between plausible climate change problems and possible actions. Early in our collaborations with Southwest installations we observed the action-oriented, “can do” attitude of personnel; interviews with representatives from the extractives industries and departments of defense in other countries showed similar action-oriented attitude, and attitudes of responsibility for attending to the costs of doing business, i.e., climate change preparedness actions.

From interviews with military personnel in the U.S. and the United Kingdom, we noted that climate change adaptation is taking place at many installations and at various scales across departments of defense; however, in the U.S., the extent of such efforts may not be fully recognized due to concerns about security. In two of our case studies, Naval Base Coronado and Fort Huachuca, actions to address projected climate changes were being planned or had been carried out; at NBC, planners have incorporated anticipated sea level rise and storm surge into siting new buildings and relocating some activities to higher floors in shoreline buildings with high exposure to these factors. At Fort Huachuca, collaborative forest management, in anticipation of existing and increased risk of fires, has been implemented—although these actions were not specifically articulated as climate change adaptation planning. In both cases, the most critical factors in translating climate change science into action were (a) making the connection between imminent, short-term risks and plausible projections that these risks would certainly not decrease, and (b) demonstrating the scientific capability to address low uncertainty short-term concerns and work with personnel to identify actionable strategies for reducing risk on multiple time scales. This approach may also satisfy requirements for “bottom line up front” (BLUF) reporting with the installation hierarchy.

***Communicating uncertainty*.** Assessing uncertainties in model projections and observations is particularly important in helping shift the response of DoD facilities from waiting to act until all information is available, to planning for climate change despite uncertainties and incomplete information. Concerns about uncertainty associated with projections of future climate are well known in the literature (e.g., Morgan et al. 2009; Rabinovich and Morton 2012). Participants in our cross-project workshop noted that uncertainties in climate are far less than uncertainties in demographics, economy, and other factors. Our review of climate change planning, preparedness, and responses in the extractives industries (e.g., oil, gas, and mineral extraction) demonstrated that these heavy industries, which are responsible for the integrity of infrastructure investments on par with those managed by the DoD, acknowledge multiple uncertainties and plan for future changes by using multiple scenarios, accompanied with monitoring and

evaluation to determine whether decision thresholds, identified in scenario planning, have been crossed (e.g., Rowland 2014; Schwartz 1991; Star 2016). The communication keys are (a) clearly communicate the array of uncertainties associated with factors that impinge on mission success, (b) focus on actions that others have taken to address similar factors and risks, and (c) normalize the discourse on uncertainty by connecting short-and-long time scales, to diffuse the perception that uncertainty is a barrier to action.

Skepticism. Skepticism about human-caused climate change is expressed by a portion of the population in the United States (e.g., Smith and Leiserowitz 2012). We encountered skeptical, but never hostile, attitudes in our interactions with DoD personnel. We demonstrated that making progress on climate change issues relies on communicating and demonstrating the strong linkages between imminent climate-related risks and evidence of plausible chances of future risks being amplified or more frequently encountered. The most important factors for addressing skepticism include focusing the initial discussions on impacts that have been experienced within the recent memory of personnel, focusing on imminent climate-related risks, and supporting suppositions with evidence. Recent literature points to an increased number of studies on the detection and attribution (D&A) of climate change factors in causing noTable weather and climate-related damages; in fact, each year, the Bulletin of the American Meteorological Society publishes a compendium of D&A studies of noTable events (e.g., Herring et al. 2015).

Opportunities. Our project team noted a number of opportunities to improve the communication of climate change information to DoD personnel. Putting climate science researchers who are familiar with DoD culture and priorities on the briefing schedule for new commanders as they engage with local leaders, fosters a first step toward normalization of climate change discourse. SERDP could play a big role in normalizing climate change communication, helping to articulate uncertainties, and highlighting both the key emerging climate-related risks, and the stories of successful implementation of adaptation actions. Expressing climate risks in terms of loss and damage related costs, highlights an opportunity to improve economic loss and damage data collection and reporting, and to emphasize the need for economists as key parts of climate science teams. While some personnel mentioned that their installations do not plan and prepare for worst-case scenarios, there is an opportunity to better communicate prospects of increases in climate-related risks, by focusing on planning commitments to short-term scenarios with low uncertainty, and to monitor and strategize for long-term scenarios. Finally, climate information has generally been developed from a research perspective and not for decision-making. For example, determining exactly what “authoritative” climate information, in a particular context, can be the subject of debate (see GAO Report 16-37 “A National System Could Help Federal, State, Local and Private Decision Makers Use Climate Information”). Developing and communicating about the authoritative DoD sources of climate information, and noting that the 14th Weather Squadron (Air Force) and the Fleet Numerical Meteorology and Oceanography Center (Navy) are two of the primary sources of information will help outside researchers and installations make more rapid progress.

5.5 Mainstreaming climate change into DoD practice and policy

From the perspective of our research and interactions with a handful of installations in the Southwest, and from the comments of participants in our cross-project workshop, if adaptation to climate change is viewed as a separate decision making process, with standalone planning documents, then it will be burdensome to the DoD. Our investigations show that the success of DoD adaptation planning will depend on integrating it with existing management and decision practices—a process known as mainstreaming (e.g., Smit and Wandel 2006; Preston et al. 2011; Uittenbroek et al. 2013); mainstreaming is already used for non-climate-related risks to operations, although the process may not be referred to using the terminology “mainstreaming.” Whereas directives from the Pentagon provide broad objectives, integration of climate-smart strategies into day-to-day practices and long-term planning processes, by uniformed officers and civilian employees at the installations is an option for success. This integration of a top-down and bottom-up strategy, combined with the flexibility to partner and gain expertise through knowledge networks and partners, will help installations navigate the complex terrain of adaptation to climate change.

5.5.1 Challenges that mainstreaming can help overcome

Climate adaptation planning requires iterative risk identification and management, a process that may take a long time to institute. Though some adaptation planning parallels activities already covered in risk and emergency management and disaster readiness plans, long-term processes that require integration of new information over time from a range of disciplines is inherently difficult. Institutional considerations (especially the rapid turnover of personnel at many bases) affect the uptake and utility of science, and the ability to manage risk. From a practical perspective, there is a need to integrate understanding of new risks and priorities associated with climate change into existing processes. Lacking funding and deadlines for consideration of climate change in operations, very little may happen to integrate climate change into existing decision processes. We learned from interviews and through our work with installation-based fire managers, that absent research and collaboration to analyze current and future situations, some climate-related risks were not apparent to staff; thus, these risks would be ignored without a process to assimilate them into existing practice. Moreover, our research pointed out that installations lack specific guidance for assessing adaptation needs and incorporating adaptation into solution sets; even within installations there are no installation-wide mechanisms for assimilating climate assessments and emerging risks. This fragmentation and lack of process hampers the ability of installations to adequately plan for future impacts, and even to incorporate no regrets strategies as systemic operational practices. Mainstreaming obviates the need to start new planning processes from scratch, and provides an avenue to make it easier to adopt low-risk or no regrets strategies.

5.5.2 Why mainstreaming is an effective strategy

The most compelling case for mainstreaming is that it fits with existing DoD and installation business and asset management practices and processes; in addition, mainstreaming aligns with incentives to institutionalize adaptation, such as self-interest with respect to BRAC, overcoming loss of institutional knowledge via staff turnover, maintaining mission readiness, and

overcoming obstacles to resilience. Our research and interviews indicate that sustainability appraisals within the UK Ministry of Defence connect with business continuity plans; this research also suggests that contract terms of reference provide a vehicle for integrating climate risk management considerations, and provide the opportunity to specify activities, including monitoring and evaluation tasks specifically aimed at gathering information on particular climate risk areas of concern. Reporting of these risks at the installation level can be achieved alongside other routine monitoring tasks, and provide an opportunity for bottom-up reporting to managers at both installation, regional and national levels. This sentiment was corroborated by participants in our cross-project workshop, who suggested that long-term contracts with private sector partners could assess how the frequency and magnitude of today's extreme events may change in the future, and document the increased future liabilities that installations may be taking on. Similar protocols are already used by the extractives industries, where climate resilience actions are mainstreamed into existing asset/project lifecycle processes. This reflects the reality that climate change risks do not usually create 'new' risks, but rather influence the likelihood and magnitude of consequence of existing risks. The co-benefit of this mainstreaming approach is that it increases the uptake of new approaches into existing risk governance and asset management procedures. Thus, mainstreaming provides an achievable and cost-effective pathway for base commanders that are interested in championing such efforts, and it can provide an opening for long-term staff when they brief incoming commanders, in terse "bottom line up front" (BLUF) statements.

Common elements of successful mainstreaming as carried out by U.S. allies' departments of defense, cities, and states include embedding mainstreaming practices throughout risk identification activities, assignment of responsibilities including reporting tasks, and collaborative partnering efforts. Mainstreaming must also be evident through the use of best available science and mechanisms to address uncertainties.

5.5.3 Overcoming barriers and sustaining mainstreaming achievements

Once mainstreamed, climate risk management should be resilient to political change. Political will to drive national priorities in managing climate risk and adaptation can vary significantly between administrative terms. As such, finding ways to build consistency of practice and continual improvement in the medium- and long-term is key to the successful delivery of adaptation goals. The New York City Mayor's office has driven the integration of climate risk management, building resilience and promoting sustainability within all its departments, including integrating climate risk activities and responsibilities in a number of job descriptions. Once these practices become the 'norm' or business as usual, they may be more likely to withstand changes in political will and the wider political landscape. This may be challenging, since top-down support for mainstreaming climate change across agencies appears to be critical. As evidenced in the UK and Australian department of defense contexts, without strengthening legislative drivers, and independent monitoring and evaluation of outcomes, measuring tangible climate resilience outcomes will be hard to achieve through piecemeal voluntary actions. An alternative way to integrate these new approaches is through the Professional Military Education (PME) curriculum across the institutions.

5.6 DoD institutional norms, leadership and partnerships

For obvious reasons the DoD must uphold a command structure and style of communication that reinforces the need to act with intent and not question command. Difficult decisions must be made and timely comprehensive action must then take place. Without this core organizational value, it would be impossible to implement action and maintain efficiency. This core organizational value may also serve as a hindrance for outside contractors and academics, particularly when the outsiders may be familiar with the latest science and technology - but unfamiliar with "how DoD business gets done."

For the DoD, *the command structure is the infrastructure that matters*. For researchers, developing a deeper understanding of military organizational leadership, institutions and potential to foster and maintain partnerships is critical for integrating experiential and empirical knowledge and enhancing continuity. Through engagement and a series of interviews conducted at various stages of the project we noted that natural resource managers (liaisons, GS-15s, and contracted civilians with permanent positions at the installations) can be viewed as "the belly button for climate related decisions" and provide an essential conduit for developing and maintaining knowledge transfer and continuity in an atmosphere that is subject to frequent leadership transitions. Credible, valued, and well respected multiyear relationships across various service components and command levels can be difficult to achieve for non-DoD personnel such as academics and private contractors who may be less familiar with military protocols and command structure. By working in tandem with both on-site natural resource managers *and* installation personnel, researchers and consultants act as the critical catalyst for the "aha moments" during which measurable shifts in perception of the utility of climate science and co-identification of risks and potential solutions takes place. In this incubational setting, installation personnel, natural resource managers and academics are able to discuss day-to-day duties, month to month goals, and year to year activities and exchange multiple perspectives and observations.

The simple act of getting the right minds together in a face to face meeting was initially a significant challenge for our team, because there was no imperative from "on high" for base personnel to engage with us. That said, once our team was able to meet with base personnel, our co-production approach allowed us to harness cumulative on-base experience and expertise, and successfully frame climate risks in a military relevance and urgency context. Our findings support the idea that communicating with and through natural resource managers, and within the existing language and organizational structure of the military promotes functional interpretation of risk - as well as clarification of direct and indirect costs that can then be easily translated up the chain of command in a format suited for DoD decision makers.

5.6.1 Academia and the institutional nature of the DoD

Challenges. As previously noted there is a fundamental disconnect between the way DoD personnel and the academic community communicate. Beyond the "loading dock" issue in which users are bombarded with an overload of data and reports that are not perceived as useful or appropriate, there is also the concept of BLUF or "bottom line up front" that persists as a barrier for successful translation between scientists and the military. During several interviews the concept of BLUF was emphasized as the predominant model for successful communication

within and between the echelons. This presents a significant challenge in that adaptive management involves flexibility for change, iterative approaches and multimodal scenarios, which may not always fit on a “one page brief” or even within the DoD “go/no go” decision making frameworks. DoD and academia are certainly not the only sectors to experience this barrier. Harmon and colleagues (2014) have also faced similar challenges in city planning in that the business and planning sectors also frequently rely on the BLUF reasoning, yet this style of communicating does not equally serve the needs of other sectors or stakeholders. Issues of information security are also limiting factors in forging relationships between academia and the military in that sharing of information, including research driven data, or updates to shared data, may not always be possible or appropriate.

Opportunities. A potential opportunity to overcome these disconnects may include involving installation level personnel and natural resource managers at the onset of project design, including grant writing and funding opportunities, so that existing DoD expertise and resources may be leveraged in the beginning/at the pre-proposal stage. This would allow projects to be co-designed to address both the needs of the DoD and researchers. Increased engagement would be required in this case and would need to be mandated or at least authorized by higher ups in order for DoD personnel to be given permission and time to be further involved in ongoing research and development as well as academic activities.

Publicly available congressional reports such as the National Security Implications of Climate-related Risks issued in July of 2015 note that geographic combatant commands (GCCs) are already guided to use theater campaign, operation, contingency and theatre security plans as a means to identify or take into account climate risks. Initiatives such as the Air Force’s 14th Weather Squadron (14WS) currently provide authoritative data sets and tailored decision aids to GCCs and assist with historical climatology and climate change near-term assessments as do NOAA and other federal agencies. Awareness of existing internal capacities at the onset of a proposal would connect researchers to the right DoD personnel and guide research protocols towards existing DoD infrastructure rather than in divergent directions.

5.6.1.1 Ensuring Continuity

As emphasized throughout this document leadership and institutional culture are interconnected factors in attaining climate adaptation success at the installation level and higher within the DoD. Not surprisingly, we found that the cooperation and interest of installation leadership is critical in any effort; however, several other factors, discussed in greater detail below, are linked strongly with leadership. Key challenges include ensuring the continuity of climate change-related projects and prioritizing adaptation efforts during the course of frequent changes in leadership. A “champion” is needed to keep up momentum in what is often a multi-year adaptation process—from planning to implementation and monitoring and developing effective partnerships and articulating the benefits of those partnerships to installation leadership. In some cases, new institutions, partnerships and networks may be required——within installations, between installations and other levels of the DoD hierarchy, and between installations, neighbors, and regional initiatives.

Challenges. Given the frequent turnover of active-duty personnel, maintaining the continuity of adaptation planning initiatives, which require sustained investments of time is a substantial challenge. One workshop participant noted that developing close, and often personal, "trusted" relationships between academics and DoD personnel is not a scalable model, because military culture shows that colonels and captains, who frequently move from assignment to assignment, execute policy and everyone above that level makes policy. Moreover, as we learned from specific interactions with personnel at NBC, external civilian communications can be perceived as a challenge because extra steps may need to be taken to assure that appropriate levels of security are maintained throughout every interaction and exchange of information.

One important avenue available to SERDP, as it aims to connect research with needs for adaptation to climate risks, is to continually foster the interest of the service liaisons, the GS-15 level personnel whose longevity and tenure at an installation usually exceeds that of commanders and other active-duty personnel. The longevity of individuals in these positions ensures continuity of institutional memory, and as we witnessed at NBC, can ensure that adaptation efforts are translated and further implemented following the transition to a new Commanding Officer. Working with long-term civilian staff can be an effective route; as one of our interviewees pointed out partnering with natural resources personnel also creates a trusted and credible relationship that may be leaned upon by new commanders, as they transition to an installation. These longer-term personnel can also assist in identifying what climate-affected actions that are already being implemented, such as hazmat training which could incorporate climate change research insights to inform tasks, such as controlling dust and other aerosols that may interfere with the health of personnel, as well as training exercises and ensuring equipment functionality. Given that installation staff are often on the "front lines" of climate adaptation, this provides an opportunity for adaptation continuity, from the bottom up.

Routes to success. *A*cademics who want to help are often blocked from gaining direct access to key decision-makers. However, if it can be demonstrated that those higher up the chain of command are interested in the work, then access may be easier. SERDP could provide guidance for researchers on how to approach the military (e.g., training and advice on the nature of the hierarchy, who makes what decisions, etc. Another route, suggested by our interviews with private and public sector entities engaged in adaptation planning, is to build institutions, such as joint civilian-DoD technical climate change panels. This strategy was employed by the New York City Mayor's Office, which convened a climate change panel to provide authoritative and robust information tailored to the needs of the entity that set the panel up. An independent panel that brings together researchers with decision makers over time can provide an opportunity for cross-learning and continuity, to overcome the high turnover of personnel. A climate change panel might also be beneficial in vetting data and information for utility in particular regions or sectors, to develop authoritative and credible sources of information and tools. The institution of a trusted panel (authorized and supported by DoD) could also help overcome the hurdle of researchers needing to establish interpersonal connections with internal "climate champions. Institutionalizing a panel could also help bridge the gap between keeping an eye on short-term concerns (readily handled by installation leadership working on a 2-3 year commitment), and longer-term concerns, which might require the attention of the 5^{th} of 6^{th} commander down the line.

Opportunities: Our research efforts found that when existing or new commanders are tasked with complying with a natural resource or environmentally centered mandate, they frequently turn to the "in house" natural resource personnel specifically because those individuals are already well established within the organization and familiar with military command, culture and protocol. Fully acknowledging the pivotal role those specific individuals are playing in climate change adaptation and further empowering these natural resource managers to learn and do more in this arena represents and important opportunity for mainstreaming climate information into base management practices. Fostering partnerships between DoD personnel, researchers, and resource liaisons may create innovative opportunities for cross-training and professional development that are systemically relevant and contextualized. Including installation-based natural resource managers in these efforts is likely to be a cost effective way forward for increasing installation-specific capacity.

5.6.2 DoD leadership challenges and opportunities

Challenges: As mentioned above, we found that the key challenges related to leadership, and advocacy within installations, for climate change adaptation are (a) frequent turnover of leaders, (b) a focus on short-term decisions, which hard-wires the system to ignore climate time-scale (years to decades) issues, (c) the need for top-down interest and or directives (i.e., political will), (d) competing priorities, and (e) ownership of the risk. Our examination of climate decision-making in organizations similarly challenged by needs for climate change adaptations, such as extractive industries and cities, shows that these issues are not unique to the DoD. Lessons emerging from the literature and interviews conducted for this report share strong similarities to well-established conditions for enabling action (IFRC 2013), that include internal and external advocacy for climate initiatives, coupled with leadership commitment, incorporation of a top-down policy and strategic framework, development institutional capacities (such as the horizontal coordination mechanisms mentioned above), and integration of climate change with the project management cycle (discussed at greater length in Section 5.5 on Mainstreaming).

Opportunities: DoD-specific opportunities to address these challenges include ensuring that those higher up the chain of command are "interested" in the work; a promising step may be briefing generals and admirals as to the urgent and relevant need for co-assessment of risk and capabilities throughout various command levels and service components. Ensuring staff continuity, or developing alternative mechanisms that can help inform new leaders (e.g., the climate panels mentioned previously), can help standardize the practice of addressing important resources-based issues, such as water and energy, on decadal or longer timescales. Involvement of midlevel management and command would also be important in minimizing disconnects between mandates and implementation. Leaders who champion climate-related concerns will spread innovations and help prioritize climate adaptation issues, by virtue of the frequent turnover in assignments. It is well known that each combatant command's assessment of risk reflects how a range of factors will affect security in its area of responsibility. What has yet to be determined is where best to insert climate change adaptation in the decision making process and to what degree additional training and research is needed to ensure long-term success.

As noted in the literature, continuing to learn is a strategic organizational choice that can be stewarded by transformational leadership and driven by an inertia of knowledge (Nourazy, 2012;

Liao, 2008; Crawford, 2005). Despite the differences between DoD and industry, learning from values and practices in an industrial context provides a template for establishing what works and what doesn't, and at what scale.

5.6.2.1 Transformational leadership: champions and early adopters

A substantial body of literature points to the important roles played by early adopters and champions of new ideas, planning processes, and technologies (e.g., Rogers 2010; Oberlack and Eisenack 2014; Carter et al. 2015). Our project points to such individuals, within installations and within the DoD hierarchy, as essential for the success of climate adaptation planning and implementation. We noted the important role of the Commanding Officer of Naval Base Coronado, at the outset of our project, in attaining buy-in from staff for prioritizing climate change adaptation and lending credibility to our project. This observation was backed by comments from interviewees, who noted that the leadership of the commanding officer in an installation strongly influences the priorities and operations of an installation, and by cross-project workshop participants who noted that, within the hierarchical structure of the DoD, "if your boss is interested you are fascinated." This was corroborated throughout our interactions with installations in the Southwest, where interest from DoD leadership, e.g., the Garrison Commander at Fort Huachuca, reinforced the early adoption of studies of potential climate change effects on wildfire regimes by civilian natural resources staff. We also noted that installation managers, staff, military-to-civilian liaisons, and civilian contractors are the "front lines" of climate adaptation in DoD, because in addition to participating in research and adopting new practices, they can shine a light on needs for improvements in management practices and planning; this was abundantly evident in our interactions with natural resource management personnel associated with climate-and-wildfire studies, and with liaisons responsible for infrastructure planning, such as at Naval Base Coronado. The actions of early adopters form the basis for "on-the-ground" interest, concern, and capacity related to climate risks through these acts of transformational leadership.

Challenges: We also noted challenges related to dependence on individual champions. First, the actions of champions are largely personality-driven; but even champions need a receptive person above them. Champions either need a receptive boss or they need to be able to "manage upwards" to create a receptive boss. Another challenge is that developing trusted relationships between researchers, early adopters, and champions takes time, and can be hit and miss, depending on the frequent turnover in enlisted personnel, and the time available to academic, government, and independent contractor researchers; without these trust relationships and timely, responsive research to inform planning and decisions, the risks co-identified by researchers and installation personnel may be ignored. Carter et al. (2015) note that interviewees in a social network analysis of success factors for urban climate change planning, pointed to the role of individual climate change champions, who were willing to use their positions to create a platform for rallying allies and achieving adaptation goals. Yet, these researchers also note that "if adaptation is led by individual champions, then cooperation that is driven forward only on this model could be at risk when individuals are removed," which was a frequently mentioned problem within our case studies and interviews. The protocol is for military personnel, especially commanders, to maintain only a 2-3 year stint at any given installation (Harmon et al. 2014). While more stability is provided by civilian employees, who provide multiple forms of expertise,

ultimately, tenants of the garrison are all temporary; thus, to spur fruitful outcomes for climate adaptation research-practitioner collaborations, partners must quickly recognize opportunities afforded by champions and early adopters, who are usually entrepreneurial individuals, and make the most of their ability to advance issues within the system.

Opportunities: Climate champions are often driven by personality, and they need a receptive person at a higher level in the organization. A positive aspect of the fact that DoD professionals move often is that if climate change champions move around, they will naturally spread innovation. Furthermore, as noted by Carter et al. (2015), knowledge can often be retained in networks, even when individual expertise moves from an organization—the aforementioned climate panels (e.g., SERDP-identified panels) could form the hub of a network that could maintain continuity and form a conduit to climate services (see below). Naval Installations Command and Air Force Installations and Mission Support Center are two examples of cross-geography (horizontal) coordination efforts (i.e., institutions) that could be useful in implementation of adaptation and resilience objectives across multiple locations.

5.6.3 Benefits and challenges of partnerships

Throughout our installation-specific case studies, workshops, and interviews, DoD personnel and participants mentioned the opportunities afforded installations and SERDP through partnerships focused on climate change adaptation. First, the pervasiveness of climate and weather effects on existing operations and the connections between hemispheric, regional and local atmospheric phenomena suggest interconnectedness between the exposure of installations and their surrounding communities to current and projected climate changes. Moreover, installations and surrounding communities share other site-specific vulnerabilities and concerns, such as those related regional water supplies, watersheds and ecosystems, transportation infrastructure and systems, storm-water runoff, and population trends. Harmon et al. note that "bottom up initiatives, such as sustainability and strategic planning at the base level, or joint base-community land use planning, tend to tug in a horizontal direction – enhancing interactions between different sub-organizations across a base and with surrounding communities and stakeholders." Similarly, we learned that the extractive industries are at risk from economic losses, damage to reputation, workforce health and safety concerns, legal and regulatory challenges—in a manner quite similar to that of installations, their surrounding civilian communities and neighboring landowners. We noted additional benefits to installations and SERDP, through information sharing, leveraging funds, and other means. We discuss these factors, the challenges and opportunities, in greater detail, below.

Challenges: First, we note the challenges posed by installation-civil society partnerships. A key challenge is in the tension between the processes that govern DoD decision-making (e.g., budget and prioritization decisions), which tend to be vertical processes, whereby traditional and well established chains-of-command dominate the process, and the horizontal decision-making suggested by the need to manage assets, or collaborate "across the fence line." Secure communications, data cyber-security, and physical infrastructure security concerns can also inhibit partnership, especially if they are perceived as undermining mission readiness, as was evidenced in our conversations with personnel at various Southwest installations. We also learned that while there are incentives for maintaining strong relations with surrounding

communities, and even symbiotic relationships—especially with respect to the robustness of local economies and institutions, such as education systems—when it comes to managing natural resources in a climate change context, partnerships can be piecemeal, as was the case with the Barry M. Goldwater Ranges, or lacking specific shared decision-making frameworks, as was the case with NBC's inland training facilities, especially when it is incumbent upon installations to serve as the primary organizer of, for example, annual landowner meetings.

Benefits and Opportunities**:** Our research demonstrated the many benefits of partnerships to ***installations.*** Whereas it is standard procedure for installations to maintain strong relationships with surrounding communities and landowners, and there are programs in place to involve stakeholders in plan review and design, such as integrated natural resources management plans (INRMP) and regional partnership initiatives, such as SERPPAS (the Southeast Regional Partnership for Planning and Sustainability), our findings show that climate change increases the need for coordinated planning and partnership. Examples of collaborative planning and review in the Southwest include at least (a) collaborations between Fort Huachuca, the U.S. Forest Service, and The Nature Conservancy to reduce wildland-urban interface risks associated with wildfires, and (b) coordination of threatened and endangered species inventory and monitoring between the Barry M. Goldwater Ranges and Cabeza Prieta National Wildlife Refuge (BLM).In both of these cases, the installation benefits from exchange of information and best practices, shared labor costs, and improved ability to assure mission readiness. Other benefits of partnerships and strong relationships with adjacent entities include (a) self-interest, when Base Realignment and Closure (BRAC) decisions are being prioritized, (b) increased resilience to weather and climate hazards, (c) reduced pressure on shared natural resources, such as water supplies, (d) added research capacity and flow of information about emerging climate-related risks and the costs of climate change impacts, and (e) improved access to decision tools.

Our investigations found parallels between installation-centered climate change planning and city government-centered climate change planning, a point corroborated in the literature (e.g., Harmon et al. 2014). Our interviews with representatives of the New York City Mayor's Office and ICLEI Local Governments showed that stakeholder engagement across a wide range of groups was a key success factor in resilience planning. As shown in our examples above, installations' outreach with stakeholders is typically limited to cooperation with statutory agencies, for example in terms of land management, or in the context of compliance with permits. As climate-induced pressures affect adjacent stakeholders and competing users of scarce and shared resources, closer and better coordinated work with these stakeholders can help installations to maintain the social license to operate—a confluence of good neighbor, increased disaster preparedness and long-term resilience benefits. In addition, our participatory climate risk assessment with NBC pointed to opportunities for NBC to work more closely with local administrations and communities (e.g., port authority, airport) to improve the urban climate-resilience of the San Diego area, and to reach out to local natural resource management agencies (e.g., the Tijuana River Estuary National Wildlife Refuge) to leverage NBC's investments in weather and climate-related planning. Participants in our cross-project workshop pointed out opportunities for enhanced partnerships, through the research needed for encroachment planning—to ensure that all the interdependencies between a facility and the community have been articulated, and to better identify all the intersections of risk and opportunity, all of which help to build joint resilience.

Fire and natural resource management staff with whom we collaborated during the course of our investigations noted that, for some installations, coordination with other agencies and landowners on fire management issues is a relatively new development and remains an informal and inconsistent process.

While there is strong interest in adopting a formal framework for quantifying climate change-related fire risk, and using tools to help plan fire response at a regional level (i.e., including participation of all surrounding land owners and fire management agencies), thus far, annual landowner meetings organized by DoD lack a specific set of objectives. Opportunities to reduce fire-related risks, e.g., at NBC's inland training facilities, opening dialogues with federal agencies (i.e., BLM and USDA-Forest Service) to discuss pooled funding for mitigating fire risks; such efforts could be amplified by including local NGOs, as was demonstrated by our example of the partnership between Fort Huachuca and The Nature Conservancy. In addition, resource and land management partnerships could foster research to develop new decision tools; as noted above, the output from decision models and research analyses access also serve to connect imminent and long-term issues—an important factor in bringing climate adaptation concerns to the forefront of installation priorities. Similarly, we learned from our interactions with the Barry M. Goldwater Ranges that partnership with neighboring federal, state, and tribal landowners can facilitate interagency agreements on standardizing methodologies for monitoring species habitat, which is projected to shift due to climate change.

We also note several benefits to the ***SERDP program***, from partnerships between researchers and installations. Interviewees pointed out that one basis for long institutional memory within the DoD is that everything is measured, and because preparedness and response actions are measurable, they can be improved, and this process is trusted; thus, one interviewee noted, new scenarios from climate scientists would be more useful if they were communicated in terms of measureable improvements in transition to operations, including improvements in efficiency and other benefits. Similarly, the interviewee suggested that the value of partnerships could be assessed if efficiency and benefits can be measured. Partnerships between natural resource personnel, university researchers and military personnel also provide a mechanism for co-identifying and improving actions that are concurrently taking place. To reinforce its investments in research, SERDP could catalyze improved climate change adaptation research interactions with installations by preparing scientists with training to understand the terminology and metrics used within the military, which are not commonplace in the academic community. Research partnerships, accompanied by workshops and debriefings, could also accelerate the development of a common set of metrics to describe and measure adaptation success. Similarly, SERDP and installations would benefit from establishing connections between installations, researchers, and contractors, due to the need to document outcomes.

The entire ***climate adaptation enterprise*** benefits from partnerships, through the following means: (a) landowners surrounding installations can focus the attention on key issues, which takes the heat off installation leadership for promoting climate adaptation, while allowing climate change ideas to be a key priority, based on concerns of surrounding communities; (b) given the turnover in installation leadership and other active-duty personnel, partnerships allow climate adaptation projects and progress to flourish, through knowledge networks, even as

individual expertise moves from an installation; (c) similarly several federal agencies have developed programs and fostered regional networks aimed at bringing scientists and stakeholders together to understand climate change risks and adaptation strategies—partnership with these climate services networks (e.g., in NOAA, DOI, USDA) can help installation infrastructure, land, and resource managers to identify risks that may not be obvious without taking into account complex, regional-scale issues, such as drought and climate change and evidence suggests that the experiences of these networks could greatly reduce the cost and ramp-up time (e.g., Lemos et al. 2014) for a DoD-wide climate program; (d) researcher-installation partnerships also form a basis for leveraging funding to accomplish the development of climate-related decision tools, adaptation indicators and metrics, and identification of innovative and cost saving approaches for implementation. This aligns well with the March 2016 cross-project workshop discussion with other SERDP teams on whether it would be most useful for DoD to expand its own internal climate services in order to promote more effective use of climate information, or whether the existing regional science teams that specialize in climate and weather services within federal partners (including those of NOAA, NASA, DOI, USDA, etc.) could be tailored for use in the military context. Other options include contract services for particular locations and challenges, but there are real limitations to this approach since it does not lead to internal capacity-building.

5.7 Providing climate services for DoD installations

The array of science-to-action data, information, forecasts, climate model projections, research, tools and practices that are commonly used to understand and manage climate-related risks is collectively referred to as *climate services* (e.g., Miles et al. 2006; Vaughn and Dessai 2014). Through our interactions with personnel at installations in the Southwest, our team found varying degrees of awareness and knowledge of the climate services available to practitioners, either through DoD channels or through federal agency and other public and private sector entities. Some were well aware of daily, monthly and seasonal data and forecast sources for their installation and region; some nearby installations needed data from just across their fence line, but had no routine means for data sharing; most were unaware of climate change data and information sources. Virtually none were aware of the tools and practices for climate risk assessment and adaptation, which follow the standard framework for iterative adaptation, and includes assessing existing and future risks and vulnerabilities, identifying and evaluating options that may be useful to address those risks and minimize impacts, implementing the priority projects, and then monitoring on an ongoing basis to learn about what approaches are most effective prior to re-assessing risks and opportunities for addressing them on an ongoing basis. The points that we emphasize here are that (a) climate services consist of far more than on-installation weather data and forecasts, and (b) an array of services are needed, and many are available (though not within the DoD), for climate adaptation risk management.

5.7.1 The need for ongoing support of DoD climate services

Climate information has generally been developed from a research perspective, without maximizing its utility for decision-making. There is a disconnect between the science and its use – for example, determining exactly what constitutes *authoritative* climate information in a particular context can be the subject of debate (see GAO Report 16-37 "A National System Could Help Federal, State, Local and Private Decision Makers Use Climate Information"). There

is some work within DoD to define what is meant by "authoritative sources of climate information." The 14th Weather Squadron (Air Force) and the Fleet Numerical Meteorology and Oceanography Center (Navy) are two of the primary internal sources for DoD climate information. These sources have strong capabilities within a limited part of the climate services spectrum, namely data, information, and forecasts; they are less well equipped to provide research, decision tools, decade-to-century scale climate model projections, translated and interpretive products, and process-based support for climate-related risk management. Moreover, personnel from Southwest installations articulated a desire for consistent climate science, in terms of (a) consistent assumptions and trend projections, and (b) alignment of DoD science with science from other Federal agencies (e.g., USGS).

5.7.2 Climate risk assessment and planning

The collective perspective of the SERDP investigators who attended our cross-project workshop was that few installations have completed rigorous climate vulnerability assessments, developed multi-sector, comprehensive adaptation plans, or implemented a full suite of risk management strategies to protect their facilities and missions from climate-related events. Given that the overall mission of the DoD involves managing risk, it is a bit ironic that this particular category of risk does not receive as much attention as many experts believe is appropriate.

5.8. Supporting DOD Climate Services Capacity:

The issue of how to most efficiently provide climate (beyond weather) services to support the DoD mission, facilities, and operation really depends on the dedication of each branch of the military to managing these risks over multiple time and space scales. One climate center cannot efficiently do all of the work to support all domestic military decision-making across all scales, let alone for global decision-making. It is possible to expand the capacity of existing personnel through a range of training efforts, but it is generally acknowledged that managing climate-related risks does require significant science background or access to science support over time; the latter point is underscored by our interactions with some Southwest installations, in which higher-ups expected staff to become experts overnight. As with climate services in other applications, the most used and useful tools and products tend to be co-produced by local, on-the-ground decision-makers and scientists who are intimately familiar with local conditions (Brooks 2013; Meadow et al. 2015); our collaborations with natural resources staff at two Southwest installations corroborates this point about co-produced tools and analyses.

5.8.1. Centralized Versus Dispersed Climate Services

Currently, a lot of weather-prediction work to support DoD is centralized to save money…but it is not clear how or whether existing internal weather-related capability (e.g., AF, USACE) can be usefully deployed in a broader climate context to maximize effectiveness in managing risks at multiple scales. Partnerships with universities and other federal agencies may be an answer to supporting the installations and operations activities locally and regionally. Emergency managers and civil engineers need to be engaged in risk management efforts as well as civil society, which means that interdisciplinary teams of social and physical scientists are likely to be useful for such exercises. Based on our interactions and interviews with personnel, there are

needs for: a Rolodex of climate services providers and topic experts (at national and region-specific scales); staff within DoD who can help identify experts in each region and make the connections; additional within-DoD capacity for translating climate science data and results into adaptation action and research questions; a dedicated body of individuals within each military branch, that is devoted to longer-term climate time scale issues and science, in order to form connections between installations and the science community; and an ability to make use of existing networks in other federal agency branches. As discussed above, an interdisciplinary, regional team supported and authorized by DoD, comprised of researchers and base personnel, could serve a useful role as advisors in these matters. Based on statements from installation personnel, there are additional needs for experts who can assist with review of climate adaptation plans and assessments of vulnerabilities.

5.8.2 Opportunities for increasing DoD climate services capacity

As noted above and elsewhere in this report, there are abundant opportunities for installations and for the DoD to partner with climate services in other Federal agencies and civil society service providers, including State Climatologists, universities, and others. The U.S. Climate Resilience Toolkit (https://toolkit.climate.gov/ and https://toolkit.climate.gov/help/partners) has links to expertise provided via Federal agencies. Installations could work with partners to develop training tools that can be delivered at low or no cost to the installation (e.g. funded by a dedicated DoD climate change budget), centered on enhancing and improving the knowledge base and capacity of personnel who tend to have longer tenures at installations (e.g. natural resources staff), as well as key service component personnel who inform and debrief base commander for example. Linking with existing climate knowledge networks and communities of practice would also facilitate information flows and provide greater access and opportunities for enhancing climate services capacity.

5.9 Research Needs and Gaps

Throughout the project cycle we were able to identify several immediate needs, as well as gaps in current understanding to provide priorities and guidance for future research projects. In terms of prioritizing more immediate needs we found that installations such as Naval Base Coronado would greatly benefit from additional co-assessment of the informational, financial and monitoring resources available for various service components. To address capacity for adapting to a changing climate, co-assessments should also include an inventory of current on-site and regional expertise. In terms of risks and loss of military capabilities associated with sea level rise, specific assessment of early warning systems and reliability of predictions should be audited. Presently there is a void in that no standard prediction model for predicting the impacts of the severe events is in use. For example, some models show a different picture than the 100 year flood scenario. There is also a need for precise elevation data and mapping efforts especially for vulnerable bases such as NBC.

During our field sessions and on site workshops we also found that financial resources are minimal or non-existent for dealing with complex sea level rise issues. There is a need to initiate the same valuation techniques used to determine and mandate funding for energy efficient buildings, to understand the benefits of taking a proactive stance that is built on collaborative and robust methods. Actual dollars, specifically earmarked for assessing, and then mainstreaming a

comprehensive adaptive approach for sea level rise risks, are needed. In the case of NBC where the installation boundaries sit within a myriad of other sectors, there is also a need to reach out to the surrounding resources and expertise of the port authority, Tijuana river managers, and airport and transportation directors. Concerted efforts to improve and increase communication across a network of stakeholders will position the DoD to leverage existing planning efforts, minimize the chronic disconnects between agencies and establish standardized federal policies that could be readily implemented and monitored. In addition to sea level rise, availability of water is also a pressing issue. Better ability to forecast is essential, particularly if you only have capability for one day of storage. An applicable lesson may be gleaned from the San Diego Foundation which funded a collaborative project on downscaling precipitation forecasts and rainwater infiltration for the water authority. The project was a success because it illuminated the need for collaboration and co-assessment in that the data the water authority had initially collected wasn't answering questions or providing solutions because the scale and format was wrong. In working with BMGR, we similarly found that there is a need for estimating habitat changes and species range changes in the face of climate change as the data are considered poor and there is insufficient modeling granularity. In addition we found that the spatial estimates being used reflected too much uncertainty. We also found that at BMGR that the physiological limits and sensitivities of species are largely unknown as biographical studies and babitat modeling is also largely underdeveloped

As previously noted, the science and tools alone do not make a successful approach. To support DoD efforts, a clear understanding of baselines in decision processes related to climate from the Pentagon and service component perspective is an important foundation for future projects. From our work we have constructed a list of pressing research gaps relevant to how the DoD should invest in working with multiple community or regional research partners to achieve adaptation and resilience outcomes:

1) DoD will benefit from framing and facilitating ongoing academic/scientific engagements with military personnel in climate-related topics. There is much to be learned here. For example, the issue of geostrategic risk assessment is relevant to military planners (e.g., connections between drought and unrest in other countries) but there are others: climate/energy; the implications of a changing Arctic; infrastructure/training; and the role of climate and risk in preparing for global humanitarian efforts. Researcher orientation training or developing a guidebook for adaptation professionals about how to engage with military would also be useful; including how the military is structured and how decisions are made, the key considerations (e.g., focus on protecting the mission), important acronyms, and cultural "dos" and "don'ts." This could result in more efficient interactions between researchers and base employees in the future. Researchers also need to know thresholds where climate modeling is relevant – e.g., weather or climate conditions that can result in shutting down an event or a mission and the frequency of shutdown, which could affect the mission in the longer term, perhaps even having BRAC implications.

2) DoD will benefit from assessing the incentives for including climate change adaptation in base management practices, including economic considerations and cost savings. Evaluating the benefits of incorporating adaptation considerations in contractor's work, especially for building and maintaining infrastructure with long life span, would be especially useful. BRAC has the potential to be a disincentive to knowing about vulnerability, yet studies of frequency, intensity,

and duration of extreme events need to be done. How can this barrier to adaptation action be overcome?

3) DoD will benefit from co-identifying and co-developing tools for managing and communicating climate-related uncertainties within DoD. For example, can scenarios or the future and successful approaches to characterizing uncertainty be developed that are both simplified and/or transferable? How can different kinds of climate data and assumptions for DoD decision makers be structured to enhance utility and an understanding of the implications for the future – what kinds of tools and language related to uncertainty works in the DoD context? The reaction of DoD employees to alternative methodologies could be tested, for example.

4) DoD will benefit from building and leveraging case studies of adaptation and asking: are there lessons that can be harvested from experiences, such as addressing sea-level rise at the Hampton Roads area/Naval Station in Norfolk that can help other installations, for example. A collection of such cases along with carefully evaluated outcomes in a DoD-relevant context would be useful. For example, we found that explaining the relationship between climate change and exposure of personnel to risk is an entry point, and a research need (casualties in current heat stress, projected trends, etc., are likely to get attention from leadership). Pilot studies of resilience efforts with FEMA and DOE under the Executive Order also provide useful learning.
5) DoD will benefit from working with researchers in experimenting with scale – broadly applicable approaches need to be tested at a pilot facility at the local scale, with the intent of promoting successful practices as appropriate across multiple facilities. There is also a need to know how to scale up using stratified selection, building a strategy that can be implemented on a broad scale. Developing this testing strategy would be an important contribution. A large number of climate adaptation tools and information sources already exist that can be evaluated for DoD utility, i.e., to help identify what is "authoritative" for use and in which contexts.
6) DoD will benefit from developing curricula for military training related to approaches to adaptation and resilience. Reviewing training programs that already exist that are related, (e.g., energy, water) is one place to start; there is a need to identify content that might go in the PME that will enhance capacity building and preparedness.

7) DoD will benefit from conducting a meta-discussion about what level of information is really needed for adaptation in a DoD context. When do you need detail and when do you not, in a decision context? How can DoD science needs be connected to the overall US research agenda in a more useful way? Generalized climate risks for different types of facilities and infrastructure would be useful, including guidelines, rules of thumb that might be applicable (inroads) as a starting place. Considering the Directive, some potential research needs could support this kind of guidance. Another example is a high-level global assessment of the impacts and implications of climate change that could be used to support combatant commanders or installations or operations? The National Security staff has been in discussions about whether there should be a report on national security and climate change, this could be an interim report within the Sustained Assessment process of the US Global Change Research Program.

8) DoD will benefit from comparing the progress of adaptation efforts with the lessons learned in environmental policy implementation on bases. Historically there was documented reluctance within DoD to implement the Endangered Species Act, etc., but eventually the

benefits of protecting species were found to be supportive of the mission of installations, and a new perspective emerged across the military. The outcome was a transition towards appreciation of the value of biodiversity and ecosystem services. This transition apparently benefitted from the influence of specific DoD leaders such as Sherry Goodman; the Sykes Act also played a role (among other contributing factors that could be documented).

9) DoD will benefit from inventorying existing access to climate data and tools (climate services). Could regional science coordination centers that provide a window into services across agencies help? Or should climate services be primarily internal to DoD? Are there external (contractor) personnel who could be trained? Should interdisciplinary researcher-DoD advisory committees be established? How should existing internal weather-related capability (e.g., AF, USACE) be deployed to maximize effectiveness in the climate context? Could partnerships be an answer to supporting the installations and operations activities more locally? Weather and space weather offices should be part of the climate preparedness conversation; emergency managers and civil engineers often need to be engaged in climate services as well.

5.10 Summary and Prospects for Implementation

Our SERDP RC-2232 project team developed and tested approaches for assessing climate-related risk, in partnership with installation personnel in pilot case studies at Naval Base Coronado, the Barry M. Goldwater Ranges, and Fort Huachuca (see Section 4). We identified an array of promising approaches for incorporating climate time-scale thinking and climate change considerations into DoD operational practices, if that continues to be a priority for the Department. Our overall guidance for climate decision-making is consistent with our original hypothesis—that best practices require direct engagement of installation personnel with researchers to identify current climate-related issues of concern, and connect them through cause-and-effect impact chains to amplified or attenuated future climate-related risks.

Once climate change-related risks were identified, prioritized, and related to mission success criteria, we demonstrated at NBC and FTH that establishing the scientific credibility of our team and working with their natural resource professionals to develop tools that are directly relevant to their decision processes is a very successful mode of engagement; this quantitative "Tier 2" level of engagement can lead to a path forward for the provision of climate services more broadly, while bridging the gap between short-term decisions in the current climate context and prospects for decisions related to changing conditions at decade-to-century time horizons of projected climate change. We also conducted interviews and convened a cross-project workshop with personnel at multiple levels in the DoD hierarchy in order to identify gaps, needs, and opportunities for infusing climate adaptation thinking and practice into DoD operations, and to evaluate promising approaches to climate services, that mesh with military culture, leadership, and practice.

Below, we articulate opportunities for implementing activities related to research recommendations:

5.10.1 Immediate opportunities

- Continued testing and evaluation of full, quantitative risk assessments, linked to existing DoD planning and emergency management protocols and guidance documents, at a broader array of selected installations
    - Evaluate existing DoD planning and emergency management protocols and guidance documents, to identify insertion points for revisions to include climate change language
- Coordination with beyond the fence line entities, e.g., local, federal, and state agency land holders, to leverage the capacities to (a) comprehensively identify climate change-related risks, and (b) provide climate services to support risk assessment and adaptation planning
- As near-term ad hoc and opportunistic climate-related decisions and adaptations are made, incorporate guidance into formal planning documents
- Incorporate climate change topics, including vulnerability and risk assessment, into Professional Military Education
    - Make the imminent risk-chronic long-term risk framing part of PME for climate change

5.10.2 Longer-term opportunities

- As near-term ad hoc and opportunistic climate-related decisions and adaptations are made, take note, and incorporate guidance into upcoming revisions of master plans, integrated natural resource management plans, and other periodically updated guidance and formal agreements
- For SERDP climate adaptation research RFP planning, require the incorporation of a broader array of expertise into research teams, especially including economists and decision analysts—in order to ground the research outputs in the explicit cost, risk, and decision frames that are most salient to DoD decision-makers
- Develop and formalize mechanisms to ensure continuity of institutional knowledge, in order to improve the chances of success for risk assessment and climate adaptation to ensure mission success
- Develop and formalize mechanisms to ensure vertical communication of climate change risk within DoD hierarchies—so installations are not blindsided by climate risks and impacts
- Coordinate climate change risk assessment frameworks with those for vulnerability analysis, and climate services (such as preferred modeling and data sets for climate change analyses)

6. Literature Cited

Abatzoglou JT. (2013). Development of gridded surface meteorological data for ecological applications and modelling. *Int. J. Climatol.* 33: 121-131.

Abatzoglou, J. T. and T. J. Brown (2012). A comparison of statistical downscaling methods suited for wildfire applications. *International Journal of Climatology* 32(5): 772-780.

Acclimatise, UK and UA SERDP Project RC-2232 Team (2015). Climate Change Impacts to Department of Defense Installations – Barry M. Goldwater Range Climate Risks Workshop Summary Report. Issued to BGR March 6, 2015.

AECOM (2016). Adaptation Planning for Sea Level Rise at Australian Defence Sites. Web document: http://www.aecom.com/projects/adaptation-planning-sea-level-rise-australian-defence-sites/ (October 2016).

Australian Government Department of Defence (2016). Defence White Paper. Commonwealth of Australia. Available from: http://www.defence.gov.au/WhitePaper/Docs/2016-Defence-White-Paper.pdf (May 2016).

Australian Government Department of Defence (2016). Integrated Investment Program. Available from: http://www.defence.gov.au/whitepaper/Docs/2016-Defence-Integrated-Investment-Program.pdf (May 2016).

Bagne, Karen E. and Finch, Deborah M. (2012). Vulnerability of species to climate change in the Southwest: threatened, endangered, and at-risk species at the Barry M. Goldwater Range, Arizona. Gen. Tech. Rep. RMRS-GTR-284. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 139 p.

Barrie, C., Steffen, W., Pearce, A., and Thomas, M. (2015). Be prepared: Climate change, security and Australia's Defence Force. Climate Council of Australia Limited. Available from: http://www.climatecouncil.org.au/uploads/fa8b3c7d4c6477720434d6d10897af18.pdf (May 2016).

Bierbaum R, Smith JB, Lee A, *et al*. (2013). A comprehensive review of climate adaptation in the United States: more than before, but less than needed. *Mitigation and Adaptation Strategies for Global Change* 18: 361-406.

Bostrom, A., et al. (2013). Targeting and tailoring climate change communications. *Wiley Interdisciplinary Reviews: Climate Change* 4(5): 447-455.

Brooks, M. S. (2013). Accelerating Innovation in Climate Services: the 3E's for climate service providers. *Bulletin of the American Meteorological Society* 94: 807–819.

Caldwell, M. R., E. H. Hartge, L. C. Ewing, G. Griggs, R. P. Kelly, S. C. Moser, S. G. Newkirk, R. A. Smyth, and C. B. Woodson. (2013). “Coastal Issues.” In *Assessment of Climate Change in*

the Southwest United States: A Report Prepared for the National Climate Assessment, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 168–196. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

CalFire. (2015). Incident database. February 10, 2015. http://cdfdata.fire.ca.gov/incidents/incidents_statsevents.

California Climate Action Team (CCAT). (2010). State of California sea-level rise interim guidance document. California: Coastal and Ocean Working Group of the California Action Team and Ocean Protection Council. http://www.slc.ca.gov/Sea_Level_Rise/SLR_Guidance_Document_SAT_Responses.pdf.

California Climate Change Center (2006). Preparing for the impacts of climate change in California: Opportunities and constraints for adaptation. Available from: http://www.energy.ca.gov/2005publications/CEC-500-2005-198/CEC-500-2005-198-SF.PDF (June 2016).

California Natural Resources Agency (2016). California Climate Adaptation Strategy. A report to the Governor of the State of California in response to Executive Order S13-2008 (2008)). Available from: http://www.energy.ca.gov/2009publications/CNRA-1000-2009-027/CNRA-1000-2009-027-F.PDF (June 2016).

Carter, J. G., et al. (2015). Climate change and the city: Building capacity for urban adaptation. *Progress in Planning* 95: 1-66.

Cavazos, T., Turrent, C., & Lettenmaier, D. P. (2008). Extreme precipitation trends associated with tropical cyclones in the core of the North American monsoon. *Geophysical Research Letters*, *35*(21).

Cayan, D., M. Tyree, K. E. K. C. Castro, A. Gershunov, J. Barsugli, A. J. Ray, J. Overpeck, M. Anderson, J. Russell, B. Rajagopalan, I. Rangwala and P. Duffy (2013). Future Climate: Projected Average. *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*. G. Garfin, A. Jardine, R. Merideth, M. Black and S. LeRoy. Washington, DC, Island Press: 101–125.

Center for Research on Environmental Decisions (CRED) (2009). The Psychology of Climate Change Communication: A Guide for Scientists, Journalists, Educators, Political Aides, and the Interested Public. New York: Columbia University, 48 p.

Chadwick, B. et al. (2015). A Methodology for Assessing the Impact of Sea Level Rise on Representative Military Installation in the Southwestern United States (RC-1703). Technical Report 2037, April 2015. San Diego: SSC Pacific, 554 p.

Chambliss, D., and Schutt, R. K. (2006). Making sense of the social world: Methods of investigation, Pine Forge, Thousand Oaks, Calif.

Chan, K. M., Guerry, A. D., Balvanera, P., Klain, S., Satterfield, T., Basurto, X., and Hannahs, N. (2012). Where are cultural and social in ecosystem services? A framework for constructive engagement. *BioScience*, 62(8), 744-756.

Chrétien, J. P. (2016). Adapting to Health Impacts of Climate Change in the Department of Defense. *Health Security*, 14(2), 86-92.

Clark, J.P. (2016). Adapting to Strategic Change: Organizational Change and Adaptation.

Coates, A. R., P. E. Dennison, D. A. Roberts, and K. L. Roth. (2015). Monitoring the Impacts of Severe Drought on Southern California Chaparral Species using Hyperspectral and Thermal Infrared Imagery. *Remote Sensing* 7:14276-14291.

Cohen, E. (2004). Change and Transformation in Military Affairs, *Journal of Strategic Studies*, 27:3, 395-407, DOI: 10.1080/1362369042000283958

Collins, L.C., (2012).Merging Science and Management in a Rapidly Changing World: Biodiversity and Management of the Madrean Archipelago III. RMRS P-67. May 1–5, 2012. Tucson, AZ U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Fort Collins, CO. pp. 40–47.

Commonwealth of Australia (2015). National Climate Resilience and Adaptation Strategy. Available from: http://www.environment.gov.au/system/files/resources/3b44e21e-2a78-4809-87c7-a1386e350c29/files/national-climate-resilience-and-adaptation-strategy.pdf (May 2016).

Crawford, C. B. (2005). Effects of transformational leadership and organizational position on knowledge management. *Journal of Knowledge Management*, 9(6), 6-16.

Creswell, J. W. (2012). Qualitative inquiry and research design: Choosing among five approaches. Sage publications.

Daly, C., M. Halbleib, J. I. Smith, W. P. Gibson, M. K. Doggett, G. H. Taylor, J. Curtis and P. P. Pasteris (2008). Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. *International Journal of Climatology* 28(15): 2031-2064.

Davis, S. D., F. W. Ewers, J. S. Sperry, K. A. Portwood, M. C. Crocker, and G. C. Adams. (2002). Shoot dieback during prolonged drought in Ceanothus (Rhamnaceae) chaparral of California: a possible case of hydraulic failure. *American Journal of Botany* 89:820-828.

DEFRA (2012). The UK Climate Change Risk Assessment 2012 Evidence Report. Available from:
http://randd.defra.gov.uk/Document.aspx?Document=TheUKCCRA2012EvidenceReport.pdf

Defra (UK Department for Environment, Food and Rural Affairs) (2012). *UK Climate Change Risk Assessment: Government Report.* Presented to Parliament pursuant to Section 56 of the

Climate Change Act 2008. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69487/pb13698-climate-risk-assessment.pdf

DeGaetano, A. T., et al. (2010). Toward Regional Climate Services: The Role of NOAA's Regional Climate Centers. *Bulletin of the American Meteorological Society* 91(12): 1633-1644.

Delamont, S. (2004). Ethnography and participant observation. *Qualitative Research Practice*, 217-229.

Dennison, P. E., D. Roberts, S. Peterson, and J. Rechel. (2005). Use of normalized difference water index for monitoring live fuel moisture. *International Journal of Remote Sensing* 26:1035-1042.

Dilling, L., and M.C. Lemos. (2011). Creating Usable Science: Opportunities and Constraints for Climate Knowledge Use and Their Implications for Science Policy. *Global Environmental Change* 21(2): 680–689.

Eakin, H., Tompkins, E.L., Nelson, D.R. and Anderies, J.M. (2009). "Hidden Costs and Disparate Uncertainties: Tradeoffs in Approaches to Climate Policy" in Adger, N.W., Lorenzoni, I. and O'Brien, K.L. (eds) (2009): *Adapting to Climate Change: Thresholds, Values, Governance*. Cambridge University Press: Cambridge.

Eden, S., (2011). Lessons on the generation of usable science from an assessment of decision support practices. *Environmental Science & Policy* 14: 11-19. doi:10.1016/j.envsci.2010.09.011

ESGF (2016). ESGF Mission. Web document: http://esgf.llnl.gov/mission.html

Falk, D.A., (2013). Are Madrean ecosystems approaching tipping points? Anticipating interactions of landscape disturbance and climate change. In: Gottfried, G.J., Ffolliott, P.F., Gebow, B.S., Eskew, L.G., Collins, L.C., *Merging Science and Management in a Rapidly Changing World: Biodiversity and Management of the Madrean Archipelago III*. RMRS P-67. May 1–5, 2012. Tucson, AZ U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Fort Collins, CO. pp. 40–47.

FERC (Federal Energy Regulatory Commission) and NAERC (North American Electric Reliability Corporation), (2012). *Arizona-Southern California Outages on September 8, 2011: Causes and Recommendations*.

Ferguson, D. B., et al. (2014). Linking Environmental Research and Practice: Lessons from the Integration of Climate Science and Water Management in the Western United States. Tucson, AZ, Climate Assessment for the Southwest: 22 p.

Fischhoff, B. (2007). Nonpersuasive Communication about Matters of Greatest Urgency: Climate Change. *Environmental Science & Technology* 41(21): 7204-7208.

Foreign and Commonwealth Office (2012). The Overseas Territories: Security, Success and Sustainability. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/14929/ot-wp-0612.pdf (June 2016).

Freedman, L. (2017). Academics and Policy-making: Rules of Engagement, *Journal of Strategic Studies*, DOI: 10.1080/01402390.2016.1269982

Frumkin, H., and A. J. McMichael. (2008). Climate change and public health: Thinking, communicating, acting. *American Journal of Preventive Medicine* 35(5):403-410.

Füssel, H.-M. (2007). Adaptation planning for climate change: concepts, assessment approaches, and key lessons. *Sustainability Science* 2(2): 265-275.

GAO (United States Government Accountability Office). (2014). Climate change adaptation. DOD can improve infrastructure planning and processes to better account for potential impacts.

Garfin, G. (2016). White Paper: Selection of Climate Data, Global Climate Models, and Climate Projections. SERDP Project RC-2232, June 15, 2016.

Garfin, G., A. Jardine, R. Merideth, M. Black, S. LeRoy. Eds. (2013). *Assessment of Climate Change in the Southwest United States*. Washington, DC: Island Press, p. 509 http://swcarr.arizona.edu/

Garfin, G., G. Franco, H. Blanco, A. Comrie, P. Gonzalez, T. Piechota, R. Smyth and R. Waskom (2014). Chapter 20: Southwest. *Climate Change Impacts in the United States: The Third National Climate Assessment*. T. C. R. J.M. Melillo, and G.W. Yohe. Washington, DC, U.S. Global Change Research Program: 462-486.

Gassman, P.W., M. R. Reyes, C. H. Green, J. G. Arnold. (2007). The Soil and Water Assessment Tool: Historical Development, Applications, and Future Research Directions. *Transactions of the ASABE*. Vol. 50(4): 1211-1250. *Geophysical Research Letters* 41:9017-9023.

Griffin, D., & Anchukaitis, K. J. (2014). How unusual is the 2012–2014 California drought?. *Geophysical Research Letters*, *41*(24), 9017-9023.

Grifman, P., Hart, J., Ladwig, J., Newton Mann, A., Schulhof , M. (2013) Sea Level Rise Vulnerability Study for the City of Los Angeles. USCSG-TR-05-2013. Available from: https://dornsife.usc.edu/assets/sites/291/docs/pdfs/City_of_LA_SLR_Vulnerability_Study_FINAL_Summary_Report_Online_Hyperlinks.pdf (July 2016).

Grimm, N. B., M. D. Staudinger, A. Staudt, S. L. Carter, F. S. Chapin III, P. Kareiva, M. Ruckelshaus, and B. A. Stein. (2013). Climate-change impacts on ecological systems: introduction to a US assessment. *Frontiers in Ecology and the Environment* 11:456-464.

Grygoruk, M., and Rannow, S. (2017). Mind the gap! Lessons from science-based stakeholder

dialogue in climate-adapted management of wetlands. *Journal of Environmental Management*, 186, 108-119.

Guertin, D.P., D.C. Goodrich, W.G. Kepner, D.J. Semmens, M. Hernandez, I.S. Burns, A. Cate, L.R. Levick, and S.N. Miller. (2008). (see pp. 49-50). Automated Geospatial Watershed Assessment (AGWA)—A GIS-Based Hydrologic Modeling Tool for Watershed Assessment and Analysis. In Norman, Laura M.,

Haidinger, T. L. and J. E. Keeley. (1993). Role of high fire frequency in destruction of mixed chaparral. *Madrono* 40:141-147.

Harmon, B., et al. (2014). Military Installations and Cities in the Twenty-First Century: Towards Sustainable Military Installations and Adaptable Cities. *Sustainable Cities and Military Installations*, Springer: 21-47.

Haworth, A. and P. Adams (2014). U.S. Department of Defense 'Climate Change Impacts to Department of Defense Installations' project. Risk report – Naval Base Coronado. (Issued to NBC) July 26, 2014. (Acclimatise, UK and UA SERDP Project RC-2232 Team)

Hayden, T. et al. (2013). Department of Army High-level Climate Change Vulnerability Assessment. Office of the Assistant Secretary of the Army (Installations, Energy and Environment). 51 pp.

HEAT Hands-On Energy Adaptation Toolkit (2010) prepared by Acclimatise for ESMAP. Source: http://www.esmap.org/sites/esmap.org/files/HEATBrochure.pdf

Herring, S. C., M. Hoerling, J. Kossin, T. Peterson, and P. Stott (2015). Explaining Extreme Events of 2014 from a Climate Perspective. *Bulletin of the American Meteorological Society* 96(12): S1-S172.

Hewitt, C., et al. (2012). The Global Framework for Climate Services. Nature Clim. Change 2(12): 831-832.

Hirsch, Derrick D., and Ward, A. Wesley, eds., Proceedings of a USGS Workshop on facing tomorrow's challenges along the U.S.-Mexico border; monitoring, modeling, and forecasting change within the Arizona-Sonora transboundary watersheds: U.S. Geological Survey Circular 1322, 63 p. [http://pubs.usgs.gov/circ/1322/c1322.pdf].

HM Government (2010). UK National Security Strategy (NSS) 2010 A Strong Britain in an Age of Uncertainty. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/61936/national-security-strategy.pdf (June 2016).

Hoerling, M. P., M. Dettinger, K. Wolter, J. Lukas, J. Eischeid, R. Nemani, B. Liebman and K. E. Kunkel (2013). Present Weather and Climate: Evolving Conditions. *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*.

G. Garfin, A. Jardine, R. Merideth, M. Black and S. LeRoy. Washington, DC, Island Press: 74-100.

Hoffman, A. J. (2010). Climate change as a cultural and behavioral issue: Addressing barriers and implementing solutions. *Organizational Dynamics*, 39(4), 295-305.

HR (House of Representatives). (2007). National Defense Authorization Act for fiscal year 2008. Washington DC: US Government Printing Office.

Hughes, M., A. Hall, and J. Kim. (2011). Human-induced changes in wind, temperature and relative humidity during Santa Ana events. *Climatic Change* 109:119-132.

Hughes, M., Mahoney, K. M., Neiman, P. J., Moore, B. J., Alexander, M., & Ralph, F. M. (2014). The landfall and inland penetration of a flood-producing atmospheric river in Arizona. Part II: Sensitivity of modeled precipitation to terrain height and atmospheric river orientation. *Journal of Hydrometeorology*, *15*(5), 1954-1974.

Hughes, P. (2016). On Convergence, Emergence, and Complexity *Military Review* 42-46. March-April 2016.

Humboldt Bay Harbor District (2016). Humboldt Bay Sea Level Rise Adaptation Planning Project. Web document available from: http://humboldtbay.org/humboldt-bay-sea-level-rise-adaptation-planning-project (July 2016).

Hungerford, R. D., R. R. Nemani, S. W. Running, and J. C. Coughlan. (1989). MTCLIM: a mountain microclimate simulation model. USDA Forest Service Intermountain Research Station, INT-414. Ogden, UT. 55 p.

IFRC (2013). A guide to mainstreaming disaster risk reduction and climate change adaptation. Available from: http://www.ifrc.org/PageFiles/40786/DRR%20and%20CCA%20Mainstreaming%20Guide_final_26%20Mar_low%20res.pdf (October 2016).

IFRC (2013). A guide to mainstreaming disaster risk reduction and climate change adaptation. Available from: http://www.ifrc.org/PageFiles/40786/DRR%20and%20CCA%20Mainstreaming%20Guide_final_26%20Mar_low%20res.pdf (October 2016)

Insurance Journal (2016). PERILS Reduces Loss Estimate to £662M for Floods from UK's Storm Desmond. March 4, 2016. Available from: http://www.insurancejournal.com/news/international/2016/03/04/400893.htm (October 2016).

IPCC (1990). First Assessment Report Climate Change: The IPCC Response Strategies - Chapter 5 Coastal Zone Management. Available from: http://www.ipcc.ch/ipccreports/far/wg_III/ipcc_far_wg_III_chapter_05.pdf (June 2016).

IPCC (2013a). *Climate Change 2013*. The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change Summary for Policymakers.

IPCC (2013b). Scenario Process for AR5. http://sedac.ipcc-data.org/ddc/ar5_scenario_process/index.html.

IPCC, (2012): *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp.

IPCC. (2014a). Chapter 2: Foundations of Decision Making. In *Climate Change (2014): Impacts, Adaptation, and Vulnerability*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Jones, R.N. et al. pp. 53

IPCC. (2014b). Summary for policymakers. In *Climate Change (2014): Impacts, Adaptation, and Vulnerability*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Field, C. et al. pp. 44

IPCC. (2014c). Chapter 1: Point of Departure. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Burkett, V. et al. pp. 35

Jacobs, K., et al. (2009). The science–policy interface: experience of a workshop for climate change researchers and water managers. *Science and Public Policy* 36(10): 791–798.

Jacobs, K., G. Garfin, and M. Lenart, (2005). More than just talk: connecting science and decision-making. *Environment: Science and Policy for Sustainable Development*, 47(9): 6-21. doi:10.3200/ENVT.47.9.6-21

Jenkins, A.P. (2016). Transforming Unit Training with the Science of Learning Military Review 99-105. November-December 2016.

Jungdahl, A. M.,and Macdonald, J. M. 2015. Innovation inhibitors in war: Overcoming obstacles in the pursuit of military effectiveness. *Journal of Strategic Studies*, 38(4), 467-499.

Kapucu, N. (2016). The Role of the Military in Disaster Response in the US. *European Journal of Economic and Political Studies*, 4(2), 7-33.

Keane, R. E., R. A. Loehman, and L. M. Holsinger.(2011). The FireBGCv2 landscape fire and succession model: a research simulation platform for exploring fire and vegetation dynamics. USDA Forest Service Rocky Mountain Research Station, Ft. Collins, CO.

Keeley, J. E. (1987). Role of fire in seed germination of woody taxa in California chaparral.

Ecology: 434-443.

Keeley, J. E. and S. C. Keeley. (1988). Chaparral. North American terrestrial vegetation:165-207.

Keeley, J. E., T. Brennan, and A. H. Pfaff. (2008). Fire severity and ecosytem responses following crown fires in California shrublands. *Ecological Applications* 18:1530-1546.

Kerr, R. A. (2011). Time to adapt to a warming world, but where's the science? *Science* 334(6059): 1052-1053.

Kirchhoff, C.J., M.C. Lemos, and S. Dessai, (2013). Actionable knowledge for environmental decision making: Broadening the usability of climate science. *Annual Review of Environment and Natural Resources*, 38(3): 1-22. doi: 10.1146/annurev-environ-022112-112828

Klein, R. J., et al. (2005). Integrating mitigation and adaptation into climate and development policy: three research questions. Environmental Science & Policy 8(6): 579-588.

Kotamarthi, R., L. Mearns, K. Hayhoe, C. L. Castro and D. Wuebbles (2016). Use of Climate Information for Decision-Making and Impacts Research: State of Our Understanding. Prepared for the Department of Defense. SERDP REPORT. Washington, DC, Strategic Environmental Research and Development Program, 55 p.

Kunkel, K. E., L. E. Stevens, S. E. Stevens, L. Sun, E. Janssen, D. Wuebbles, K. T. Redmond and J. G. Dobson (2013). Part 5. Climate of the Southwest U.S. NOAA Technical Report. Washington, D.C., National Oceanic and Atmospheric Administration. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: 79 p.

LANDFIRE. (2016). LANDFIRE LFDAT 2.6 National Fire Data Program. USDA Forest Service and U.S. Department of the Interior, Geological Survey. Web Page. http://www.landfire.gov/.

Lemos MC, Rood RB (2010) Climate projections and their impact on policy and practice. *Wiley Interdiscip Rev Clim Change* 1:670–682

Lemos, M. C., and B. J. Morehouse. (2005). The Co-Production of Science and Policy in Integrated Climate Assessments. *Global Environmental Change* 15(1): 57–68.

Liao, S. H., Fei, W. C., & Liu, C. T. (2008). Relationships between knowledge inertia, organizational learning and organization innovation. *Technovation*, *28*(4), 183-195.

Lyle A. 2012. DOD must have petroleum fuel alternatives, official says. American Forces Press Service. July 11. U.S. Department of Defense website. http://archive.defense.gov/news/newsarticle.aspx?id=117084

MACA. (2014). Multivariate Adaptive Constructed Analogs (MACA) Statistical Downscaling

Method. University of Idaho. September 20, 2014. http://maca.northwestknowledge.net/.

Mahmoud, M., et al. (2009). A formal framework for scenario development in support of environmental decision-making. *Environmental Modelling & Software* 24(7): 798–808.

Maurer, E. P., L. Brekke, T. Pruitt and P. B. Duffy (2007). Fine-resolution climate projections enhance regional climate change impact studies. *Eos Trans. AGU* 88(47): 504.

McKenzie, E., Posner, S., Tillmann, P., Bernhardt, J. R., Howard, K., & Rosenthal, A. (2014). Understanding the use of ecosystem service knowledge in decision making: lessons from international experiences of spatial planning. *Environment and Planning C: Government and Policy*, 32(2), 320-340.

McNie, E.C., (2013). Delivering climate services: Organizational strategies and approaches for producing useful climate-science information. *Weather, Climate, and Society*, 5(1): 14–26. doi:10.1175/WCAS-D-11-00034.1

Meadow, A. M., Ferguson, D. B., Guido, Z., Horangic, A., Owen, G., & Wall, T. (2015). Moving toward the deliberate coproduction of climate science knowledge. *Weather, Climate, and Society*, *7*(2), 179-191.

Means III, E., M. Laugier, J. Daw, L. Kaatz, and M. Waage. (2010). *Decision Support Planning Methods: Incorporating Climate Change Uncertainties into Water Planning*. Report of the Water Utility Climate Alliance. San Francisco: 102 p.

Mearns, L. O., et al. (2013). Climate change projections of the North American Regional Climate Change Assessment Program (NARCCAP). *Climatic Change* 120(4): 965-975.

Meehl, G.A., C. Covey, T. Delworth, M. Latif, M. McAvaney, J.F.B. Mitchell, R.J. Stouffer, and K.E. Taylor. (2007). The global coupled model dataset: A new era in climate change research. *Bull. Amer. Meteor. Soc.* 88, 1383-1394, doi: 10.1175/BAMS-88-9-1383

Melillo JR, Richmond TC and Yohe GW (Eds.). (2014). *Climate change impacts in the United States: The third national climate assessment.* US global change research program, 841 pp.

Metroeconomica, (2004). Costing the impacts of climate change in the UK: overview of guidelines. UKCIP Technical Report. UKCIP, Oxford

Meyer, R. (2012). Finding the True Value of US Climate Science. *Nature* 482: 133.
Miles, E. L., et al. (2006). An approach to designing a national climate service. Proceedings of the National Academy of Sciences *103*: *19616-19623*.

Miller, N. L. and N. J. Schlegel. (2006). Climate change projected fire weather sensitivity: California Santa Ana wind occurrence. *Geophysical Research Letters* 33.

Mills-Knapp, S.,Bourdeau, E., Falco, G. , Resler,C., Tovar, H., and Zoegall, S. (2011). Climate

Change Adaptation and Sustainable Design at the Port Authority of New York & New Jersey. Available from: http://www.earth.columbia.edu/sitefiles/file/education/capstone/Capstone_final_5_11_11_reduced.pdf (May 2016).

Morgan, G., et al. (2009). *Best Practice Approaches for Characterizing, Communicating, and Incorporating Scientific Uncertainty in Decision-making.* A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. *Synthesis and Assessment Product*. Washington, DC, NOAA. 5.2.

Moser, S. C. (2010). Communicating climate change: history, challenges, process and future directions. Wiley Interdisciplinary Reviews: *Climate Change*, 1(1), 31-53.

Moser, S., (2009). Making a difference on the ground: the challenge of demonstrating the effectiveness of decision support. *Climatic Change*, 95: 11–21. doi:10.1007/s10584-008-9539-1

Moss et al. (2010). The next generation of scenarios for climate change research and assessment. *Nature* 463(7282): 747-756.

National Audit Office (2007). Ministry of Defence – Managing the Defence Estate: Quality and Sustainability. Available from: https://www.nao.org.uk/report/managing-the-defence-estate-quality-and-sustainability (June 2016).

National Park Service (2010). National Park Service Climate Change Response Strategy, 36 pp., U.S. National Park Service Climate Change Response Program, Fort Collins, Colorado. [Available online at http://www.nature.nps.gov/climatechange/docs/NPS_CCRS. pdf]

National Research Council (2004). *Adaptive Management for Water Resources Project Planning*. Washington, DC, The National Academies Press.

National Research Council (2010). *Adapting to the Impacts of Future Climate Change*. America's Climate Choices: Panel on Adapting to the Impacts of Climate Change: Katharine L. Jacobs and Thomas J. Wilbanks (co-chairs).Washington, DC, National Academies Press.

National Research Council. (2009). *Decision Support and Learning. Informing Decisions in a Changing Climate*. Chapter 3. Washington, DC: The National Academies Press.

Naval Base Coronado website (2017). http://www.cnic.navy.mil/ (Accessed 16 February 2017)

Naval Facilities Engineering Command (2010). Naval Base Coronado Activity Overview Plan

Neiman, P. J., Ralph, F. M., Moore, B. J., Hughes, M., Mahoney, K. M., Cordeira, J. M., & Dettinger, M. D. (2013). The landfall and inland penetration of a flood-producing atmospheric river in Arizona. Part I: Observed synoptic-scale, orographic, and hydrometeorological characteristics. *Journal of Hydrometeorology*, *14*(2), 460-484.

Neuman, W. L. (2000). *Social research methods: Qualitative and quantitative approaches*, Allyn and Bacon, Needham Heights, Mass.

Northern Hydrology & Engineering (2015). Humboldt Bay: Sea Level Rise, Hydrodynamic Modeling, and Inundation Vulnerability Mapping. Report prepared for State Coastal Conservancy, and Coastal Ecosystems Institute of Northern California. Available from: http://humboldtbay.org/sites/humboldtbay2.org/files/Final_HBSLR_Modeling_InundationMapping_Report_150406.pdf (July 2016).

Obama B. (2013). Preparing the United States for the impacts of climate change. Executive Order 13653. November 6.

Obama B. (2009). Federal leadership in environmental, energy, and economic performance. Executive Order 13514. October

O'Connor, C., Falk, D. and G. Garfin (2015) Projected climate change impacts on vegetation, fire, and wildlife habitat at Fort Huachuca, Arizona. Preliminary Report. June 2015. Tucson, University of Arizona, 34 p.

O'Connor, C., Sheppard, B., Falk, D. and G. Garfin. (2016a). SERDP RC-2232 Interim Report 2: Quantifying post-fire flooding risk associated with changing climate at Fort Huachuca, Arizona. Technical Report to Ft. Huachuca, Department of the Army. March 2016. Tucson, University of Arizona, 33 p.

O'Connor, C., Treanor. F., Falk, D. and G. Garfin (2016b). SERDP RC-2232 Interim Report 3: Climate change-type drought, temperature, and fire effects on Naval Base Coronado inland training sites, San Diego County, California. January 2016. Tucson, University of Arizona, 29 p.

Office of the Governor of the State of California (2005). Executive order S-3-05. Available from: https://www.gov.ca.gov/news.php?id=1861 (June 2016).

Office of the Governor of the State of California (2008). Executive Order S-13-08. Available from: https://www.gov.ca.gov/news.php?id=11036 (June 2016).

Park, F. (2016). A Rigorous Education for an Uncertain Future *Military Review* 70-77. May-June 2016.

Port of San Francisco (2016). Strategic Plan 2016-2021. Available from: http://sfport.com/sites/default/files/Executive/Docs/StrgcPlan_for%20review.pdf (June 2016).

Preston, B. L., et al. (2011). Climate adaptation planning in practice: an evaluation of adaptation plans from three developed nations. Mitigation and Adaptation Strategies for Global Change 16(4): 407-438.

PRISM. (2013). PRISM Climate Group, Oregon State University. http://www.prism.oregonstate.edu/

Rabinovich, A. and T. A. Morton (2012). Unquestioned Answers or Unanswered Questions: Beliefs About Science Guide Responses to Uncertainty in Climate Change Risk Communication. *Risk Analysis* 32(6): 992-1002.

Rollins, M. G. (2009). LANDFIRE: a nationally consistent vegetation, wildland fire, and fuel assessment. International Journal of Wildland Fire 18:235-249.

Romero-Lankao, P., Smith, J., Davidson, D. , Diffenbaugh, N., Kinney, P., Kirshen, P., Kovacs, P. and Villers Ruiz, L. (2014). North America. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1439-1498. Available from: https://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-Chap26_FINAL.pdf (June 2016).

Rowland, E., M. Cross, and H. Hartmann. (2014). Considering Multiple Futures: Scenario Planning to Address Uncertainty in Natural Resource Conservation. Washington, DC, U.S. Fish & Wildlife Service. http://www.fws.gov/home/climatechange/pdf/Scenario-Planning-Report.pdf

Schneider, S.H., S. Semenov, A. Patwardhan, I. Burton, C.H.D. Magadza, M. Oppenheimer, A.B. Pittock, A. Rahman, J.B. Smith, A. Suarez and F. Yamin, (2007). Assessing key vulnerabilities and the risk from climate change. *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 779-810

Schwartz, P. (1991). *The Art of the Long View: Planning for the Future in an Uncertain World*. New York, Doubleday.

Scott, J. H. and R. E. Burgan. (2005). Standard fire behavior fuel models: a comprehensive set for use with Rothermel's surface fire spread model. RMRS-GTR-153, USDA Forest Service, Rocky Mountain Research Station., Fort Collins, CO.

Scott, J. H., M. P. Thompson, and D. E. Calkin. (2013). A wildfire risk assessment framework for land and resource management. General Technical Report RMRS-GTR-315, USDA Forest Service Rocky Mountain Research Station.

SERDP (Strategic Environmental Research and Development Program) (2010). *Climate Change Impacts to Department of Defense Installations*. FY 2012 Statement of Need. Resource Conservation and Climate Change (RC) Program Area. SON Number: RCSON-12−02. October 28, 2010.

Sheffield, J., A. P. Barrett, B. Colle, D. Nelun Fernando, R. Fu, K. L. Geil, Q. Hu, J. Kinter, S.

Kumar, and B. Langenbrunner. (2013). North American Climate in CMIP5 Experiments. Part I: Evaluation of Historical Simulations of Continental and Regional Climatology. *Journal of Climate* 26: 9209-9245.

Sheppard, S. R., et al. (2011). Future visioning of local climate change: A framework for community engagement and planning with scenarios and visualisation. *Futures* 43: 400-412.

Sheppard, S. R., Shaw A, Flanders D, Burch S, and Schroth O. (2013). Bringing Climate Change Science to the Landscape Level: Canadian Experience in Using Landscape Visualisation Within Participatory Processes for Community Planning. *Landscape Ecology for Sustainable Environment and Culture*, Springer: 121-143.

Slovic, P. (2000). *The perception of risk*. London: Earthscan.

Slovic, P., Finucane, M. L., Peters, E., et al. (2004). Risk as analysis and risk as feelings: Some thoughts about affect, reason, risk and rationality. *Risk Analysis, 24,* 311-322.

Smit, B. and J. Wandel (2006). Adaptation, adaptive capacity and vulnerability. Global *Environmental Change* 16: 282-292.

Smith, J. B., J. M. Vogel, T. L. Cruce, S. Seidel, and H. A. Holsinger, (2010). Adapting to Climate Change: A Call for Federal Leadership. Pew Center on Global Climate Change, Arlington, VA. [Available online at http://www.c2es.org/docUploads/adaptation-federal-leadership.pdf]

Smith, N. and A. Leiserowitz (2012). The Rise of Global Warming Skepticism: Exploring Affective Image Associations in the United States Over Time. *Risk Analysis* 32(6): 1021-1032.

Smith, R.E., D.C. Goodrich, and J.N. Quinton, (1995). Dynamic, distributed simulation of watershed erosion: The KINEROS2 and EUROSEM models, Journal of Soil and Water Conservation, 50(5):517-520.

Snover, A.K., L. Whitely Binder, J. Lopez, E. Willmott, J. Kay, D. Howell, and J. Simmonds. (2007). *Preparing for climate change: a guidebook for local, regional, and state governments*. University of Washington, Seattle, Climate Impacts Group. In association with and published by ICLEI – Local Governments for Sustainability, Oakland, CA.

Spradley, J. P. (2016). The ethnographic interview. Waveland Press.

Star, J., et al. (2016). Supporting adaptation decisions through scenario planning: Enabling the effective use of multiple methods. *Climate Risk Management* 13: 88-94.

Terriff, T. (2006a). ‘Innovate or die’: Organizational culture and the origins of maneuver warfare in the United States Marine Corps. *Journal of Strategic Studies*, 29(3), 475-503.

Terriff, T. (2006b).Warriors and Innovators: Military Change and Organizational Culture in the

US Marine Corps. *Defence Studies* 6(2): 215-247.

The British Army (2016). HQ British Forces Germany. Web document: http://www.army.mod.uk/structure/27886.aspx (June 2016).

The British Army (2016). The British Army in Africa. Web document: http://www.army.mod.uk/operations-deployments/22724.aspx (June 2016).

The City of New York (2007). plaNYC: A Greener, Greater New York. Available from: http://www.nyc.gov/html/planyc/downloads/pdf/publications/full_report_2007.pdf (June 2016).

The City of New York (2013). plaNYC: A Stronger, More Resilient New York. Available from: http://s-media.nyc.gov/agencies/sirr/SIRR_singles_Hi_res.pdf (June 2016).

The City of New York (2014). One New York. The Plan for a Strong and Just City. Available from: http://www1.nyc.gov/html/onenyc/index.html (October 2016).

The Port Authority of New York & New Jersey (2015). Design Guidelines Climate Resilience. Available from: https://www.panynj.gov/business-opportunities/pdf/discipline-guidelines/climate-resilience.pdf (May 2016).

The Port Authority of New York & New Jersey (n.d.). Adapting to Climate Change: Practical Strategies at the Port. Presentation by Christopher Zeppie, Director, Office of Environment and Energy Programs Port Authority of New York and New Jersey. Available from: https://www.panynj.gov/about/pdf/NYSA-Adaptation-Presentation.pdf (May 2016).

Thomas, M. (2012). Assessing the Risk of Global Climate Change on the Australian Defence Force. E-International Relations, March 8 2012. Web document: http://www.e-ir.info/2012/03/08/assessing-the-risk-of-global-climate-change-on-the-australian-defence-force/ (May 2016).

Thomson, I. & Boutilier, R. G. (2011). Social license to operate. In P.Darling (Ed.), *SME Mining Engineering Handbook* (pp. 1779-1796). Littleton, CO: Society for Mining, Metallurgy and Exploration.

Tidwell, V. C., L. Dale, G. Franco, K. Averyt, M. Wei, D. M. Kammen, and J. H. Nelson. (2013). “Energy: Supply, Demand, and Impacts.” In *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 240–266. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

UA SERDP Project RC-2232 Team (2014) White Paper on Risk Assessment Methodology. Prepared by Project RC-2232 projct for the Strategic Environmental Research and Development Program.

Uittenbroek, C. J., et al. (2013). Mainstreaming climate adaptation into urban planning: overcoming barriers, seizing opportunities and evaluating the results in two Dutch case studies. *Regional Environmental Change* 13(2): 399-411.

UK Government (2008). Climate Change Act 2008: Part 4 Impact and adaptation to climate change. Available from: http://www.legislation.gov.uk/ukpga/2008/27/contents/enacted (October 2016).

UNDP. (2009). (1st published in 2002). "A Climate Risk Management Approach to Disaster Reduction and Adaptation to Climate Change." In *The Earthscan Reader on: Adaptation to Climate Change,* edited by Schipper, E. Lisa F. and Ian Burton. London: Earthscan.

UNISDR (2005). *Hyogo framework for action 2005-2015: building the resilience of nations and communities to disasters*. Extract from the final report of the World Conference on Disaster Reduction (A/CONF. 206/6).

UNISDR (2016). Sendai Framework for Disaster Risk Reduction 2015-2030. Web document: http://www.unisdr.org/we/inform/publications/43291

UNISDR ARISE (n.d.). Adaptation and Planning Strategies to Mitigate the Impact of Climate Change Induced Sea Level Rise, Flooding and Erosion at Selected Australian Department of Defence Sites. Available from: http://www.unisdr.org/files/49459_aecom.australia.pdf

United Kingdom Ministry of Defence (2010). MoD Climate Change Delivery Plan. Available from: http://webarchive.nationalarchives.gov.uk/20121026065214/http://www.mod.uk/NR/rdonlyres/AFAFEF28-1CFB-44F2-BCCC-15ABB00766D9/0/MoDClimateChangeDeliveryPlan2010FINAL.pdf (May 2016).

United Kingdom Ministry of Defence (2012). Building a Climate Resilient Estate - A Practitioner Guide. Defence Infrastructure Organisation. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/33599/20120529PG01_12BuildingaClimateResilientEstateFinalv10U.pdf (October 2016).

United Kingdom Ministry of Defence (2015). Sustainability & Environmental Appraisal Tools Handbook. Section 7: Climate Impact Risk Assessment Methodology (CIRAM). Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/469114/20151016_Section-7_O.pdf (May 2016).

United Kingdom Ministry of Defence (2016). Strategy for Defence Infrastructure 2015-2030. Strategy for the Infrastructure Defence Line of Development. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/568181/20161111-Strategy_for_Defence_Infrastructure_2015-2030.pdf (May 2016)

United Kingdom Ministry of Defense (2015) Sustainability & Environmental Appraisal Tools Handbook Section 6: Defence Related Environmental Assessment Methodology (DREAM).

Available from:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/469113/20151016_Section-6_O.pdf (February 2017).

US DoD (United States Department of Defense). (2016). DoD Directive 4715.21: climate change adaptation and resilience. Released by the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics. Issued January 14, 2016. Washington, DC: Department of Defense.

US DoD (United States Department of Defense). (2014). The 2014 Climate change adaptation roadmap. Released by the Office of the Deputy Under Secretary of Defense for Installations and Environment (Science & Technology Directorate) June 2014. Washington, DC: Department of Defense.

US DoD (United States Department of Defense). (2010). Quadrennial Defense Review Report. February 2010. Washington, DC: Department of Defense.

U.S. Department of the Air Force and U.S. Department of the Navy (USAF & USN) (2013). Integrated Natural Resources Management Plan: 2012 Update. Prepared by: U.S. Department of the Air Force, Luke Air Force Base and U.S. Department of the Navy, Marine Corps Air Station Yuma, in cooperation with U.S. Department of the Interior, Fish and Wildlife Service, Cabeza Prieta National Wildlife Refuge, and Arizona Game and Fish Department.

U.S. Navy (2006). Installation Emergency Management Program Manual (CNI 3440.17). 23 January 2006.

USGS. (2015b). U.S. Geological Survey Long Term Archive January 8, 2015. https://lta.cr.usgs.gov/get_data/.

Van Vuuren, D. P., J. Edmonds, M. Kainuma, K. Riahi, A. Thomson, K. Hibbard, G. C. Hurtt, T. Kram, V. Krey, J.-F. Lamarque, T. Masui, M. Meinshausen, N. Nakicenovic, S. J. Smith and S. K. Rose (2011). The representative concentration pathways: an overview. *Climatic Change* 109(1): 5-31.

Vaughan, C. and S. Dessai (2014). Climate services for society: origins, institutional arrangements, and design elements for an evaluation framework. *Wiley Interdisciplinary Reviews: Climate Change* 5(5): 587-603.

Villarreal, M. L., et al. (2016). Modeling Landscape-scale Erosion Potential Related to Vehicle Disturbances Along the USA–Mexico Border. *Land Degradation & Development* 27(4): 1106-1121.

Vose, R. S., S. Applequist, M. Squires, I. Durre, M. J. Menne, C. N. Williams Jr, C. Fenimore, K. Gleason, and D. Arndt. (2014). Improved historical temperature and precipitation time series for US climate divisions. *Journal of Applied Meteorology and Climatology* 53:1232-1251.

Walker, A. H., Pavia, R., Bostrom, A., Leschine, T. M., & Starbird, K. (2015). Communication practices for oil spills: Stakeholder engagement during preparedness and response. *Human and Ecological Risk Assessment: An International Journal*, 21(3), 667-690

Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, P. Thorne, R. Vose, M. Wehner, J. Willis, D. Anderson, S. Doney, R. Feely, P. Hennon, V. Kharin, T. Knutson, F. Landerer, T. Lenton, J. Kennedy, and R. Somerville (2014). Ch. 2: Our Changing Climate. In J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe (eds.), *Climate Change Impacts in the United States: The Third National Climate Assessment*. Washington, DC: U.S. Global Change Research Program, 19-67. doi:10.7930/J0KW5CXT.

Weaver, C. P., Lempert, R. J., Brown, C., Hall, J. A., Revell, D., & Sarewitz, D. (2013). Improving the contribution of climate model information to decision making: the value and demands of robust decision frameworks. Wiley Interdisciplinary Reviews: *Climate Change*, 4(1), 39-60.

Weber, E. U. (2006). Experience-based and description-based perceptions of long-term risk: why global warming does not scare us (yet). *Climatic Change*, 77(1-2), 103-120.

Weeks, D., et al. (2011). Climate change scenario planning: A tool for managing parks into uncertain futures. *Park Science* 28(1): 26-33.

Weng, Q. ed., (2011). *Advances in Environmental Remote Sensing: Sensors, Algorithms, and Applications*. CRC Press.

Wilby, R. L. and Dessai, S. (2010), Robust adaptation to climate change. Weather, 65: 180–185. doi: 10.1002/wea.543

Wilhite, D. A., M. J. Hayes, and C. L. Knutson. (2005). Drought Preparedness Planning: Building Institutional Capacity. *In* D.A. Wilhite (ed.) *Drought and Water Crises: Science, Technology, and Management Issues.* pp. 93-135. CRC Press, Boca Raton, FL.

Wilhite, D. A., M. J. Hayes, C. L. Knutson, and K. H. Smith. (2000a). The Basics of Drought Planning: a 10-Step Process. Lincoln, NE, National Drought Mitigation Center, 14 p.

Wilhite, D. A., M. J. Hayes, C. L. Knutson, and K. H. Smith. (2000b). Planning for Drought: Moving From Crisis to Risk Management. *Journal of the American Water Resources Association* 36 (4):697-710.

Williams, B. K., et al. (2009). Adaptive management. *Technical Guide. The US Department of the Interior* 172.

Willows, R. and R. Connell (eds.) (2003). Climate adaptation: risk, uncertainty and decision-making. *UKCIP Technical Report*. U. K. C. I. Program. Oxford, United Kingdom Climate Impacts Program: 154 p.

Wood, M. D., Bostrom, A., Bridges, T. and Linkov, I. (2012), Cognitive Mapping Tools: Review and Risk Management Needs. *Risk Analysis* 32: 1333–1348. doi:10.1111/j.1539-6924.2011.01767.x

Youberg, A. and P. Pearthree. (2011). Post-Monument Fire floods and debris flows in the Huachuca Mountains, southern Arizona. Available from: http://azgeology.azgs.az.gov/article/environmental-geology/2011/09/post-monument-fire-floods-and-debris-flows-huachuca-mountains

7. Appendices

7.1 Data and Supporting Materials

Appendix A: Types of questions asked during UA interviews

UA Questionnaire

- *Describe your general duties and responsibilities or tasks associated within your service component.*
- *What types of events may interfere with your general duties, training exercises or overall mission readiness?*
- *Do you feel that your service component faces challenges specifically related to climate change?*
- *How well is your service component postured or prepared to address climate change mitigation (management of greenhouse gas emissions for example)?*
- *What sources of climate change information do you currently rely on?*
- *How do you currently identify and assess the risks associated with climate change that may interrupt or halt completion of your duties/training/daily operations/management of facilities/mission readiness?*
- *Who is responsible for developing new policy/procedural directives within your service component or installation?*
- *How does your service component communicate and implement new policy/procedural directives at various command levels?*
- *What are the barriers to implementing new policy/procedural directives?*
- *Are you familiar with the DoD Directive 4715.21 - Climate Change Adaptation and Resilience?*
- *How do you envision integrating new requirements related to managing climate risks (e.g. managing greenhouse gas emissions) that are included in DoD Directive 4715.21 and recent executive orders?*
- *What mechanism(s) does your service component use to ensure critical information is transferred during leadership transitions?*
- *Do you feel there is a need for personnel that focus specifically on climate change adaption at your installation or as part of your service component? (a civilian or active military personnel role similar to a natural resources liaison or scientific specialist who focuses on wildlife, water conservation, etc,.)*
- *If so, what specific tasks would you expect them to focus on (what would be the priority) to best support your service component?*
- *What resources or tools would help your service component to be more prepared to take on adaptation measures?*
- *At what command level or professional development phase do you see an opportunity to include education and training components focused on climate change related risks?*

Appendix B: Types of questions asked during Acclimatise interviews

	Acclimatise, UK Questionnaire
1	• What are the primary drivers that led your organization to start managing risks from a changing climate? • What is the general level of awareness of climate risk management in your organization? • How does this compare to awareness of managing current weather-related risks?
2	• What is the level of appreciation that climate change is also an incremental risk over the longer term? Does your organization think about critical thresholds, and how financial, design, operational and safety margins may gradually be eroded / encroached over the longer term? (e.g. Air-conditioning / cooling power demand)
3	• What are the primary barriers your organization encountered when addressing climate change risks?
4	• What organizational change measures, if any, were implemented, to facilitate your evaluation of climate risks? • At what level were these changes implemented? • In your opinion, was this at the correct level, or should it have been higher up / lower down the chain of command? • Is it feasible for individual sites to take this challenge on themselves? Would this be seen as a positive innovative action, or, a negative distraction from daily duties?
5	• What climate risk assessment methodologies do you use, or know about? Are these stand alone, or designed to be integrated within your existing procedures? • Do you look to any other sectors for risk assessment best practice / steerage? If so, which sectors, and why?
6	• Which external stakeholders are involved in developing your risk assessment methodologies and procedures, and why? • Have any of your stakeholders specifically promoted / requested the inclusion of climate change as a risk consideration?
7	• In undertaking climate risk evaluation, how did your organization obtain a) information/ data, b) budget approval for the work, c) technical capacity to undertake the work? • Which internal personnel were consulted when undertaking your climate risk evaluation, and why? • Were external stakeholders involved in the climate risk evaluation, or decisions on adaptation actions that should be implemented?
8	• How are risk assessment outcomes reported, actions sanctioned and process/ success measured? • Who, if anyone, is involved in making the various decisions/ approvals within your organization specifically pertaining to climate risk management and adaptation?
9	• How do you deal generally with the concept of uncertainty in day-to-day activities and forward planning? • Do you think dealing with uncertainty helps with thinking through uncertainty related to climate change? If not, why do you think the conceptual thinking is not easily transferrable to climate change?
10	• How are implemented measures selected, monitored & evaluated? • How is success measured? Is there one success factor that outweighs all others?
11	• We are looking for case studies that demonstrate real action in this area to include in our review. Are there any examples you could supply (non-confidential reports etc.)?

Appendix C: Naval Base Coronado Risk Report 2014

Acclimatise, UK and UA SERDP Project RC-2232 Team (2014). Climate Change Impacts to Department of Defense Installations – Naval Base Coronado Climate Risk Report. Issued to NBC July 26, 2014.

ACCLIMATISE
building climate resilience

US Department of Defense

‘Climate Change Impacts to Department of Defense Installations’ project

Risk report – Naval Base Coronado

(Issued to NBC)

July 26, 2014

THE UNIVERSITY OF ARIZONA

Report for
University of Arizona

Our reference 50028

Authored by

Anna Haworth and Peter Adams

Approved by

Bob Khosa

Acclimatise
Hexgreave Hall
Farnsfield, Newark
Nottinghamshire
NG22 8LS

T: +44 (0) 1623 884347
F: +44 (0) 5603 105079
E: a.haworth@acclimatise.uk.com
W: www.acclimatise.uk.com

Contents

1. Context and purpose

1.1. Introduction to the project

Climate change will affect Department of Defense (DoD) operations, DoD's stewardship responsibilities as well as its relationships with other agencies, the private sector and the local communities and environment within which it operates. The University of Arizona (UA), in partnership with Acclimatise (a UK-based climate change adaptation consultancy), is working on a project to support the DoD to integrate climate risk into their operational planning, asset management and strategic objectives.

Using Naval Base Coronado (NBC) as a case-study pilot, we are working in partnership with DoD managers and external agencies to develop robust approaches to climate change risk assessment and adaptation, all of which are supported by a set of climate adaptation tools that can be used across DoD operations.

1.2. Introduction to the risk assessment

In line with best practice in decision-making and policy-setting, this assessment of climate risks for DoD installations has been developed using a risk-based approach. The purpose of the risk assessment is to quantify as accurately as possible the probable impact of known climate risks to NBC and the wider San Diego area, in order *"to identify a safe level or rate of change, or at least a socially acceptable level of risk to be avoided"*[1]. Because a risk assessment approach prioritizes credibility and cost-efficiency, it is much more likely to gain traction with the decision-makers in situations where there are known and immediate risks[2]. In other words, it suggests to decision-makers that adaptation efforts are best directed at issues for which the risks are fairly well understood, with sufficient weight of scientific evidence to justify action. The outputs from the risk assessment form the evidence base for understanding decision-makers' needs, which is a crucial first step to ensure that climate data products are tailored to the specific user requirements.

The climate change risk assessment for NBC identifies risks to the installation's function and mission caused by physical changes in climate conditions. It is important to highlight that the assessment is high-level, i.e. at the installation-wide scale, based solely on a one-day workshop and not detailed one-to-one consultation activities with operational, managerial and financial experts. In order to increase the specificity of the risks identified for individual installations within NBC, a more detailed, quantitative assessment would need to take place, employing extensive consultation, spatial analysis tools, and sensitivity and exposure analyses, amongst other methods. This type of detailed assessment would provide the level of granularity needed to begin identifying the priority risks related to mission success.

1.3. Structure of this report

Following this introduction, the report is divided into five additional sections, with four appendices.

Sections 2 and **3** provides background context for the risk assessment, namely:

- Section 2: an overview of NBC in with a short narrative of its location, function and mission and success criteria, as drawn from literature and engagement activities; and
- Section 3: provides details of the current climate in the Southwest United States and outlines two future climate scenarios: warmer and drier conditions with occasional heavy rainfall; and higher sea level and higher wave surge.

Section 4 outlines the climate change risk assessment methodology, with details of the data collection process, risk assessment and prioritization criteria.

Section 5 forms the main discussion of the climate-related risks and opportunities and is organized under the following headings:

- "Top" risks, where the risks that are positioned at the top of the aggregated risk ranking exercise (Appendix 4) are presented;
- Opportunities;
- Direct climate impacts to Mission Essential Infrastructure, Assets and Services;
- Direct climate impacts to Force Protection and Safety;
- Direct climate impacts on the Environment and Regulatory Requirements;
- Direct climate impacts on Local Communities and Public Relations;
- Cascading consequences for Training and Operational Readiness; and
- Cascading consequences for Emergency Preparedness.

Section 5 also contains a number of case studies, highlighting how past weather-related events have affected NBC's operations and assets. These were drawn from facilitated sessions with NBC personnel at a climate change workshop held in May 2013. Their purpose is to act as "eye openers" about the potential weather-related risks facing NBC today, how the installation dealt with them and the lessons learned in the context of future climate change. It is not intended to explicitly make the link between these events and climate change; the case studies are designed to serve as reflective examples, rather than predictions for the future.

Additional information on the background and rationale for the risk assessment framework, workshop materials, the Installation Emergency Management Program Manual (CNI 3440.17) and full risk register are provided in Appendices 1, 2, 3 and 4 respectively.

2. Overview of Naval Base Coronado (NBC)

2.1. Location

NBC is the largest command in the southwest region of the United States comprised of the main site Naval Air Station North Island (NASNI) and seven special areas, shown in Figure 1 and outlined in Table 1. The eight installations employ more than 27,000 military and civilian personnel and encompass more than 57,000 acres, combining airfields, ports, training ranges and facilities to provide critical operational training and services for the entire Navy under one command. For this risk assessment, the distinction has been made between "coastal" and "mountain" installations; the assessment does not go to the level of detail of individual installations.

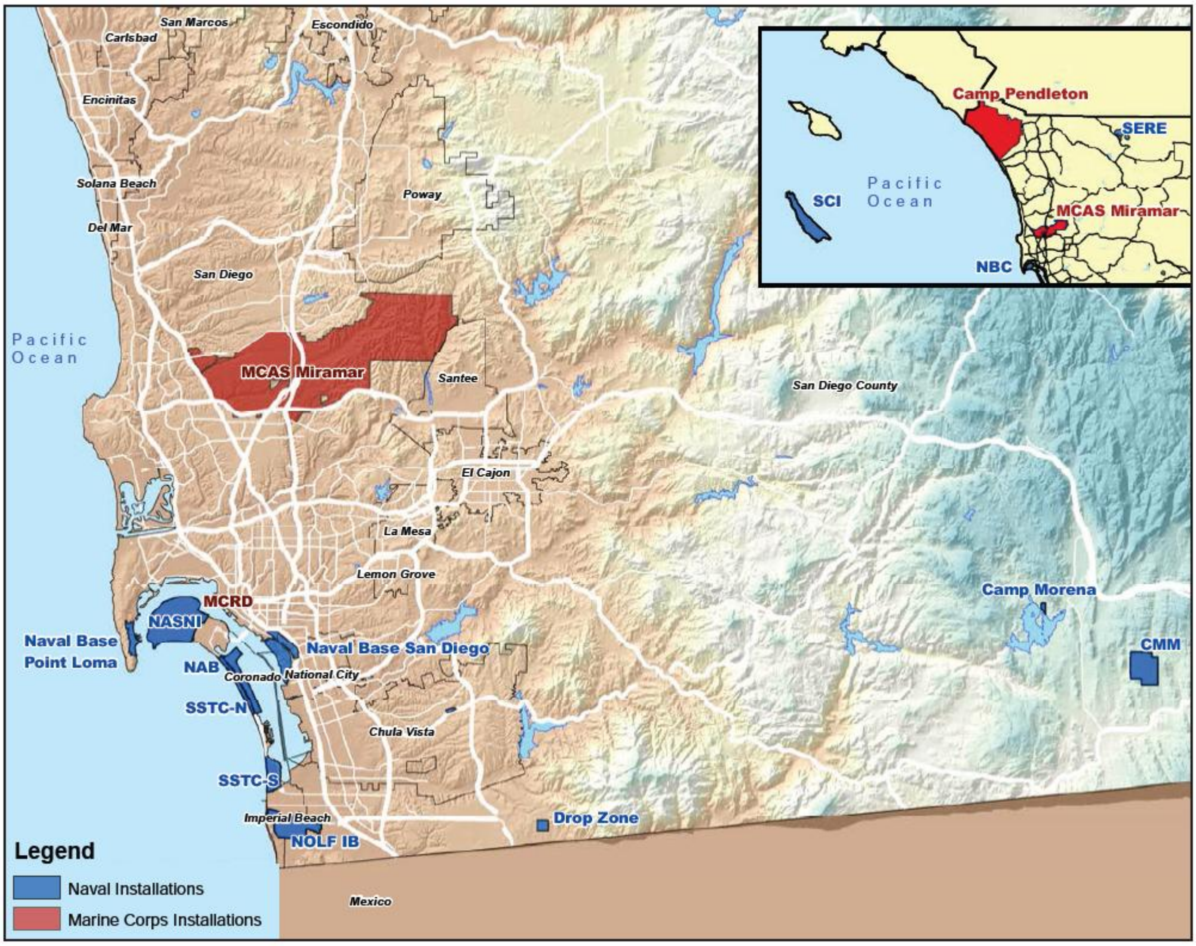


Figure 1: NBC and surrounding military installations[3]

Table 1: Installations forming part of NBC[3 & 4]

Installation	Location	Size	Functions / notes
Naval Air Station North Island (NASNI)	Southwest of Downtown San Diego and adjacent to the City of Coronado	2,397 acres of land area and 406 acres of water	• Host to 23 squadrons and 80 additional tenant commands and activities • Only Navy airfield on the West Coast that is collocated with the piers serving its fleet carriers • Direct air access for aircraft needing to reach

Installation	Location	Size	Functions / notes
			ships offshore
NBC Naval Amphibious Base (NAB)	Southeast of NASNI, on the Silver Strand and in the middle of the municipal limits of the City of Coronado	1,091 acres on both water and land	• West Coast hub for naval amphibious operations, including training and special warfare. • State Route 75 (SR-75) bisects NAB
Silver Strand Training Complex (SSTC)	Imperial Beach / Coronado border	450 acres	• Premier training facility for the military's special forces • Waterborne approaches from both the Pacific Ocean and San Diego Bay sides. The city-like layout of the base also provides a realistic site for critical urban warfare training • Land leased from the State of CA
NBC Naval Outlaying Landing Field (NOLF), Imperial Beach (IB)	10 miles south of NAB on the U.S.-Mexico border, within the City of Imperial Beach and is 14 miles south of Downtown San Diego	1,257 acres	Functional components and their associated areas: • Airfield and airfield easements (1,256 acres), • Mowed grasslands around the airfield (242 acres), • Roads and developed areas (276 acres), • Leased agriculture/grazing (128 acres), • Leased land to Department of Labor Job Corps Center, (25 acres), and • Remaining portion of the base is managed by the U.S. Fish and Wildlife Service (USFWS) as a part of the Tijuana River National Estuarine Research Reserve/Tijuana Slough National Wildlife Refuge
NBC Naval Auxiliary Landing Field (NALF), San Clemente Island (SCI)	Pacific Ocean approximately 68 nautical miles west of San Diego	37,000 acres	• Provide readiness training for units and personnel who deploy overseas • Ranges off the SCI shores – the primary range covers over 149,000 square miles and is the Navy's busiest fleet airspace
Camp Michael Monsoor (CMM), La Posta	50 miles east of San Diego, south of Interstate 8 (I-8) and north of State Route 94 (SR-94)	1,079 acres	• Complex includes an administration building, 5 firing ranges, a close quarters combat training complex, classrooms, and barracks • Located on Bureau of Land Management (BLM) land • Bordered on the north by the Cleveland National Forest and BLM lands on the south, east, and west
Camp Morena, La Posta	North of Lake Morena County Park, near Campo, San Diego County	-	• Mountain and cold weather training

Installation	Location	Size	Functions / notes
Survival, Evasion, Resistance and Escape Training School (SERE) Facility, Warner Springs	Northeastern San Diego County, at an elevation of about 3200 feet. Located in Cleveland National Forest	-	• Camp consists of a headquarters area with an administrative building, several staff barracks buildings, a wastewater treatment plant and a training compound

2.2. Function and mission

NBC's mission is to arm, repair, provision, service and support the U.S. Pacific Fleet and other operating forces[3]. In order to support the Fleet, Fighter and Family, NBC's goal is: *"to provide the highest quality base operating support and quality of life services to U.S. Navy operating forces and other assigned and visiting activities. We seek to provide the right support, at the right time, in the right amount, enabling operating forces to produce the right level of combat readiness."*[5]

2.3. Success criteria

One of the opening sessions at the climate change adaptation workshop held at NBC in May 2013 focused on defining NBC's key objectives and success criteria. The purpose of drawing out this information is that it is important to understand the broad objectives and success criteria for the NBC installations, so that the causal chains linking success or failure to climatic factors can be identified. Each functional group identified their own decision-making criteria, although a number of common themes emerged, including maintaining operational and training readiness, compliance with legislation and regulations and delivering cost-efficient services (Table 2).

Table 2: NBC's success criteria, as identified by the four workshop break-out groups. Comparable criteria have been placed in rows across the table.

Operations	Training	Facilities	Environment
Operational Readiness	-	Operable runways, roads & harbor for training and missions	-
		Durability and cost-efficiency of new construction	
Training Readiness	-	-	-
Force Protection	Safety	-	-
Mission Essential Services	-	Uninterrupted power and water supply	-
		Continued operation of IT and communications infrastructure	
Emergency Preparedness	Communication with other Groups on and off	-	-

	Base		
	Mitigating encroachment	-	-
	Working with imposed Legislation/Regulations	-	Compliance

The full list provided in Table 2 has been reduced in number and grouped into the following success criteria:

- Mission Essential Infrastructure, Assets and Services;
- Force Protection and Safety;
- Environment and Regulatory Requirements;
- Local communities and Public Relations;
- Training and Operational Readiness; and
- Emergency Preparedness.

These success criteria form the organizing structure of Section 5, where the risks identified through stakeholder engagement and desk-based review are grouped and discussed under these headings.

3. A changing climate for the Southwest United States

According to the Intergovernmental Panel on Climate Change (IPCC), man-made climate change is already underway. Globally, changes in physical and biological systems are already being observed and will intensify over the coming decades. Based on the latest National Climate Assessment, the Southwest is expected to continue warming throughout 2100, with **longer and hotter heat waves** in summer and **more intense, severe, and frequent droughts**[6]. These changes will have profound impacts on the natural environment, coastal ecosystems and communities, water resources, energy, agriculture, urban areas, human health and trans-border issues. This section outlines the observed changes in the current local climate and presents future climate projections.

3.1. Current climate

This section explores some of the recent observed climatic changes in the Southwest related to changes in temperature, precipitation and consequential observed changes to river flows.

3.1.1. Temperature

Many locations in the Southwest have experienced **warmer temperatures** in recent decades, compared to the 1901-1960 average (Figure 2). Since the 1990s, average temperatures have been over a degree Fahrenheit, or roughly 0.5 degrees Celsius, higher for the region than the 1901-1960 average. The inset graph in Figure 2 shows that the period from 2001 to 2011 was warmer than any previous decade in the region.

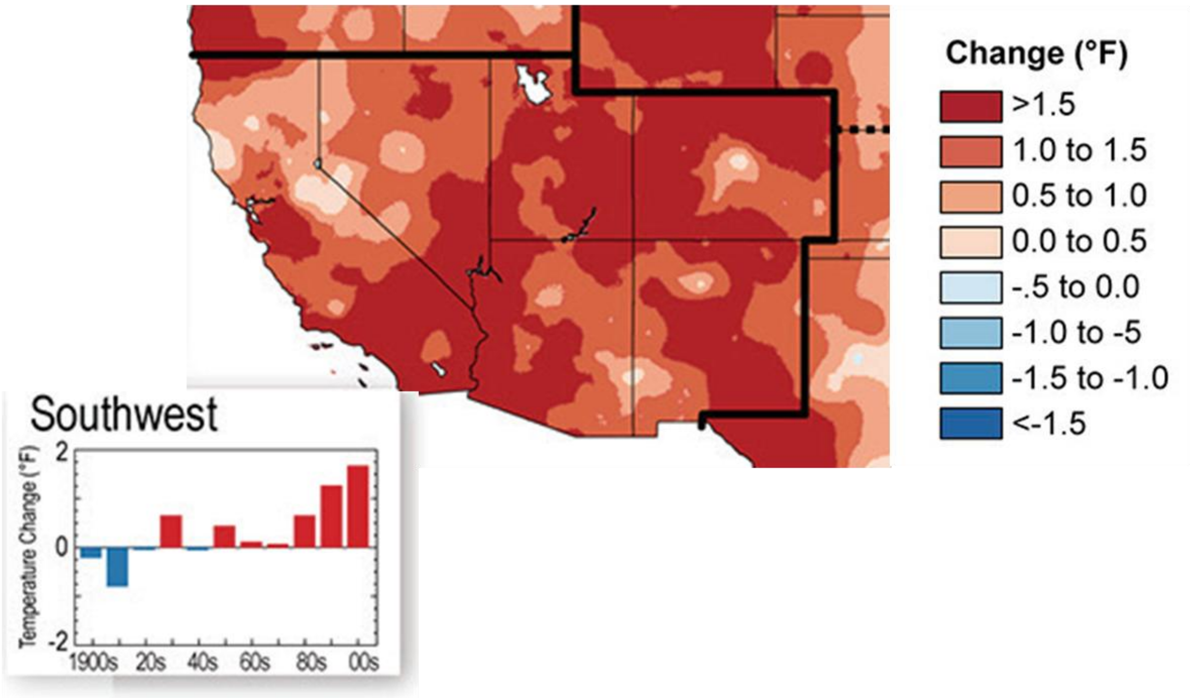


Figure 2: Map shows temperature changes over the past 20 years in °F (1991-2011) compared to the 1901-1960 average[7]. Inset graph show the average temperature changes by decade for 1901-2011 (relative to the 1901-1960 average) for the Southwest region (Data source: NOAA NCDC / CICS-NC)[8].

Concurrent with this warming in average temperatures, there has been a decrease in the number of cold snaps and an increase in the number of heat waves[i] during recent decades (Figure 3). The

[i] Defined as four-day periods that are colder and warmer than the threshold of a one in-five-year occurrence. The thresholds are computed for the entire 1901–2010 period.

increase in the heat wave index in recent decades even surpasses the conspicuously warm period during the 1930s. An important thing to note at this point is that relatively small shifts in mean climatic conditions, like warmer temperatures, can lead to relatively large changes in the occurrence of extreme events, like heat waves.

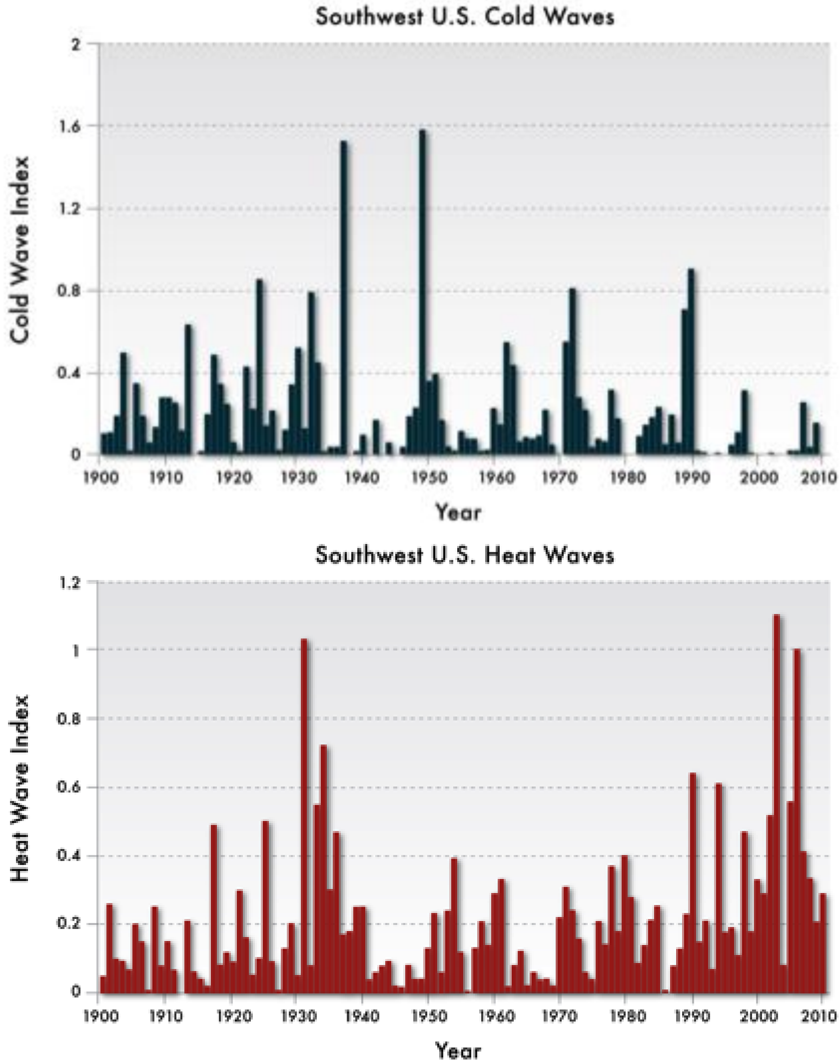


Figure 3: Frequency of temperature extremes – cold snaps (upper) and heat waves (lower) (Data source: NOAA National Climatic Data Center for the Cooperative Observer Network http://www.ncdc.noaa.gov/land-based-stationdata/cooperative-observer-networkcoop)[9].

3.1.2. Precipitation

There is less of a discernible trend in precipitation across the Southwest region in recent decades, as indicated in Figure 4 by the positive and negative percent changes in annual totals, compared to the 1901-1960 average. The inset graph shows differences in average precipitation for the region by decade, which shows an equally variable pattern. For regional precipitation extremes in the context of very heavy daily rain events[ii], there is no clear trend across the region over the past century (Figure 5).

[ii] Defined as the heaviest 1% of all daily events from 1901 to 2011.

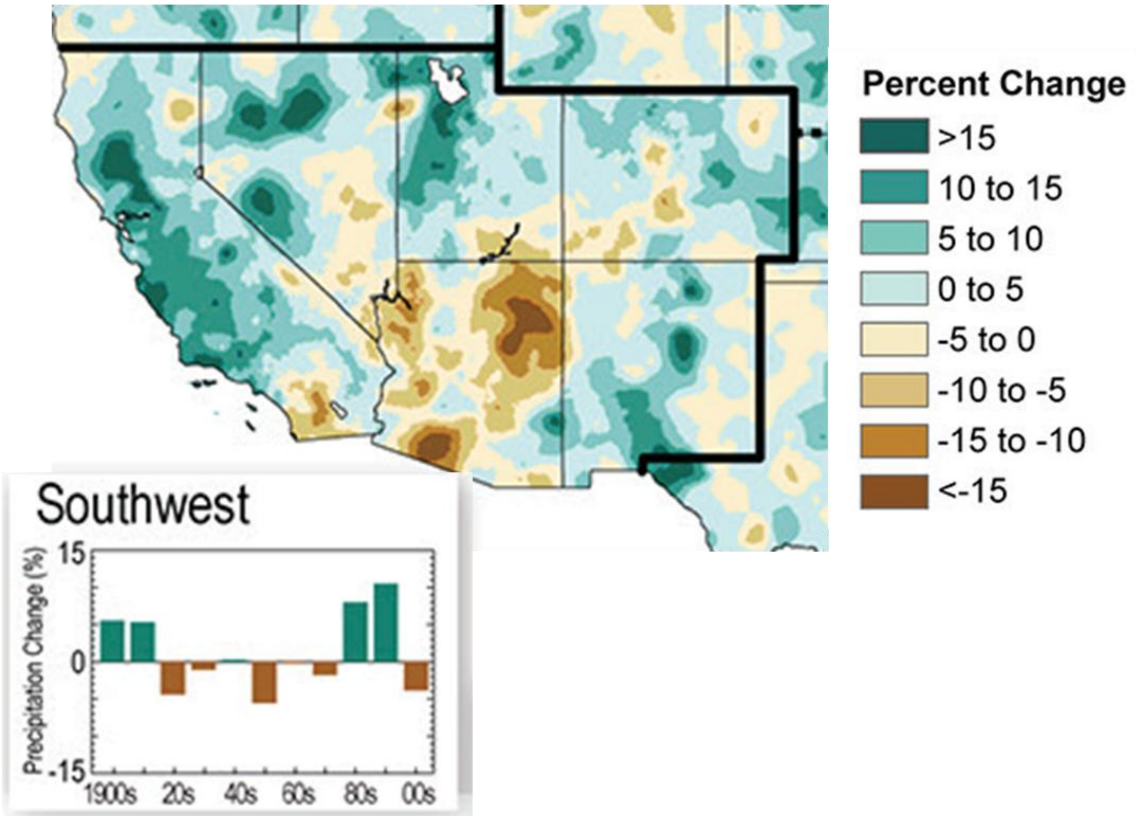


Figure 4: Map shows annual total precipitation changes (percent) for 1991-2011 compared to the 1901-1960 average, and show wetter conditions in most areas (Source: McRoberts and Nielsen-Gammon 2011)[10]. Inset graph shows average precipitation differences by decade for 1901-2011 (relative to the 1901-1960 average) for each region (Data source: NOAA NCDC / CICS-NC)[11].

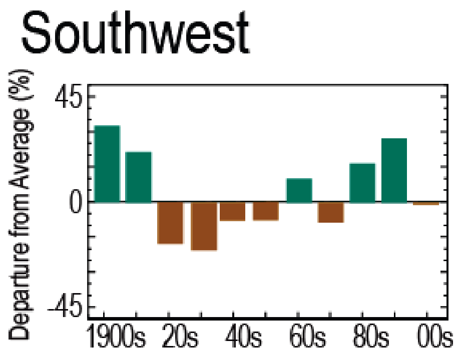


Figure 5: Changes in annual precipitation falling in *very heavy* events, compared to the 1901-1960 average (Data source: NOAA NCDC / CICS-NC)[12].

3.1.3. River flows

The water supply for many cities in the Southwest, including San Diego, is heavily dependent on rivers. Recent flows in the four major drainage basins of the Southwest have been lower than their twentieth century averages[13]. Table 3 shows the differences in precipitation, temperature, and streamflow for the decade of the 2000s compared to the 1900s for the four major river basins in the region. In general, the lower streamflows for the 2000s are beyond what would be expected alone from reduced precipitation – as for the first three river basins – or from slightly increased precipitation – as for the Rio Grande. The lower streamflows also in part could be reflecting

hydrological changes symptomatic of a warmer climate – much like regional observations of earlier snowmelt and losses in snowpack.

Table 3: Differences between 2001–2010 and twentieth-century averages of basin-mean precipitation, average temperature, and streamflow for four major hydrologic basins in the Southwest[14].

River Basin	Periods Compared	Precipitation Difference	Temperature Difference	Streamflow Difference
Colorado River at Lees Ferry (naturalized)	2001-2010 vs 1901-2000	- 4%	+ 1.3°F (+ 0.7°C)	- 16%
Sacramento-San Joaquin Rivers (naturalized)	2001-2010 vs 1931-2000	- 7%	+ 1.3°F (+ 0.7°C)	- 37%
Humboldt River at Palisade, NV	2001-2010 vs 1921-2000	- 3%	+ 1.3°F (+ 0.7°C)	- 5%
Rio Grande at El Paso	2001-2010 vs 1941-2000	+ 3%	+ 1.1°F (+ 0.6°C)	- 23%

3.2. Future climate scenarios

In climate change research, scenarios describe plausible trajectories of different aspects of the future that are constructed to help investigate the potential consequences of man-made climate change[15]. Scenarios represent many of the major driving forces including processes, impacts (physical, ecological and socioeconomic), and potential responses that are important for informing climate change policy. The goal of working with scenarios is not to predict the future but to better understand uncertainties and alternative futures, in order to consider how robust different decisions or options may be under a wide range of possible futures[15]. They are used to develop and test decisions under a range of plausible futures; this approach strengthens an organization's ability to recognize, adapt to, and take advantage of changes over time[16].

The two future scenarios explored in this risk assessment are:

1. Warmer and drier with occasional heavy rainfall; and
2. Higher sea level and higher wave surge.

Each of these scenarios is described in more detail below, with each section opening with a "headline messages" box. The potential future annual average changes in temperature (as degrees Fahrenheit or Celsius) and precipitation (as % change) have been organized into three successive time periods for this century, 2021-2050, 2051-2070 and 2071-2099. The changes are relative to the baseline period of 1971-2000.

3.2.1. Warmer and drier with occasional heavy rainfall

Scenario headline messages:

- Temperatures rise substantially over this century, with greater warming in summer than winter. High temperatures occur more frequently.
- Precipitation declines slightly. Year-to-year and decade-to-decade variations still result in wet spells and droughts. Heavy precipitation events become more common.
- Warmer temperatures and decreased precipitation reduce snowpack, which lowers streamflow in major river basins.

	2021-2050	2051-2070	2071-2099
temperature*	+ 2°F (+ 1.1°C)	+ 4°F (+ 2.2°C)	+ 7°F (+ 3.9°C)
precipitation*	- 2%	- 3%	- 3%

*Annual change in average from 1971-2000[17]

Some climate change is certain to occur in the Southwestern U.S. One way to visualize projected changes is by describing aspects of a given site's future climate in terms of another site's current climate. For example, in San Diego, 2 degrees Fahrenheit above annual average would be akin to the current annual average temperature in Los Angeles, while plus 4 degrees Fahrenheit in San Diego would make it more like Twentynine Palms, and plus 7 degrees Fahrenheit is akin to the climate of Casa Grande, Arizona, which is between Tucson and Phoenix. Similarly for the annual change in average precipitation, 2% less than the San Diego average would align with the current annual average in Elko, Nevada, while 3% less would be similar to that in Las Cruces in southern New Mexico.

However, there are further climatic variations not captured by the simple exercise of transferring existing aspects of average annual climate of one region to another. Other potential areas of change, such as the seasons during which warming is focused, would lead to impacts that cannot be determined from simple analogies to hotter or drier locations. In Figure 6 for example, across all of the future time periods, the greatest increases in temperature occur during summer, while in winter the smallest increases occur. These temperature projections, compared to the 1971-2000 reference period, are based on a relatively high emissions scenario which assumes emissions continue with little reduction or on a 'business-as-usual' trajectory. The spread is based upon a fifteen-model average of mean seasonal temperature changes for early-, mid-, and late-21st century, relative to the reference period. Such seasonal variation further complicates a scenario where change is greater and/ or harder to predict than simply variations in precipitation and temperature.

Information Box: Emissions scenarios

This report uses the established Intergovernmental Panel on Climate Change (IPCC) greenhouse gas emissions scenarios, A2 (high) and B1 (low). These scenarios were used as inputs into global climate models to project climate changes in the IPCC Fourth Assessment Report and are fully described in the Special Report on Emissions Scenarios[18].

Increases in the accumulation of greenhouse gases in the atmosphere are thought to be the main cause of twenty-first century climate change stemming from human economic development

choices. While greenhouse gases are not the only influence on climate change considered by the IPCC, estimating the amount of greenhouse gases in the future atmosphere is probably the largest uncertainty in projecting future climate.

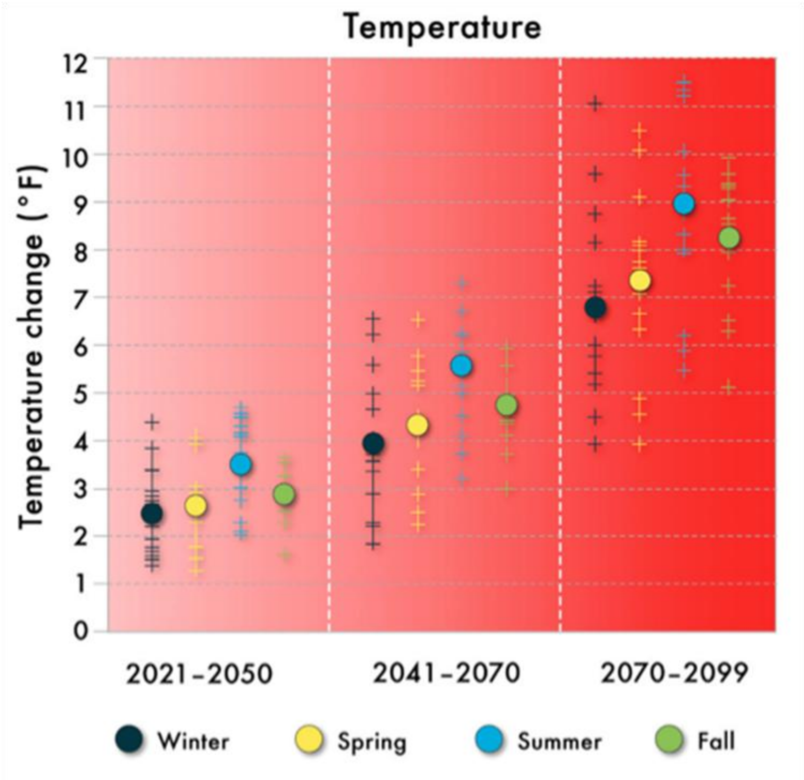


Figure 6: Projected change in average seasonal temperatures for the Southwest region in the high-emissions (A2) scenario. Plus signs are projected values for each individual model and circles depict overall means[19]. (Data source: Mearns et al. (2009)).

Temperature increases will also lead to an increased frequency of heat waves. As shown in Figure 7, a high emissions scenario projects increases in the annual maximum number of consecutive days when maximum temperatures are above a particular threshold, in this case, 95 °F (35 °C). Under a scenario of relatively high greenhouse gas emissions (A2), periods of maximum daily temperatures greater than 95 °F would increase an additional one to two weeks in San Diego County during the middle of this century, compared to the 1971-2000 reference period (shown by the blues and greens on the map).

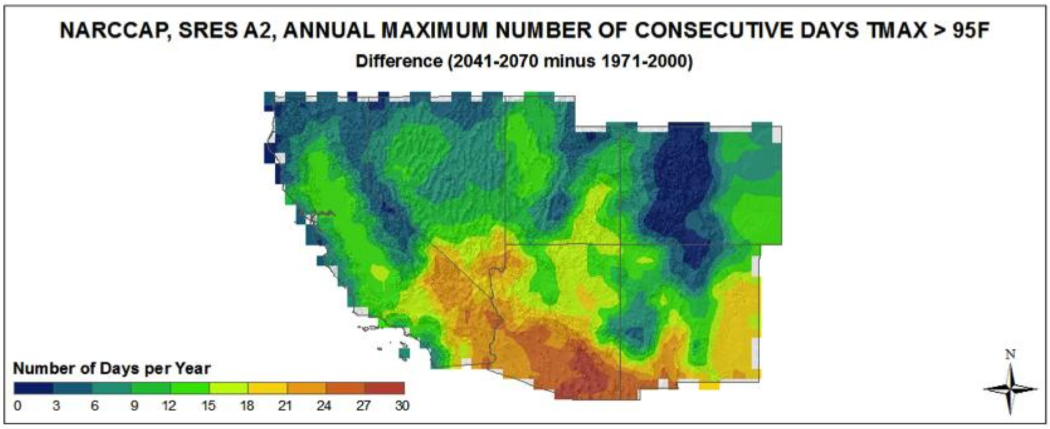


Figure 7: Projected annual mean difference in the number of consecutive days with a maximum temperature greater than 95°F (TMAX > 95°F) for the Southwest region[20]. These fields are multi-model means from the 9 NARCCAP regional climate simulations for the high (A2) emissions scenario.

Decreases in precipitation will also vary across seasons. For example, in Figure 8, declining seasonal precipitation under a high greenhouse gas emissions scenario (A2) will be more significant in spring than in winter. Total declines by the end of the century are projected to range from -10% to more than -30% in seasonal precipitation, compared to the 1901-1960 reference period.

Wet regions will tend to become wetter while dry regions become drier. In general, the northern part of the U.S. is projected to see more winter and spring precipitation, while the Southwest is projected to experience less precipitation. This regional drying trend during these seasons will be driven in part by the jet stream's shift to the north, shunting storm systems – and the precipitation they deliver – away from the Southwest.

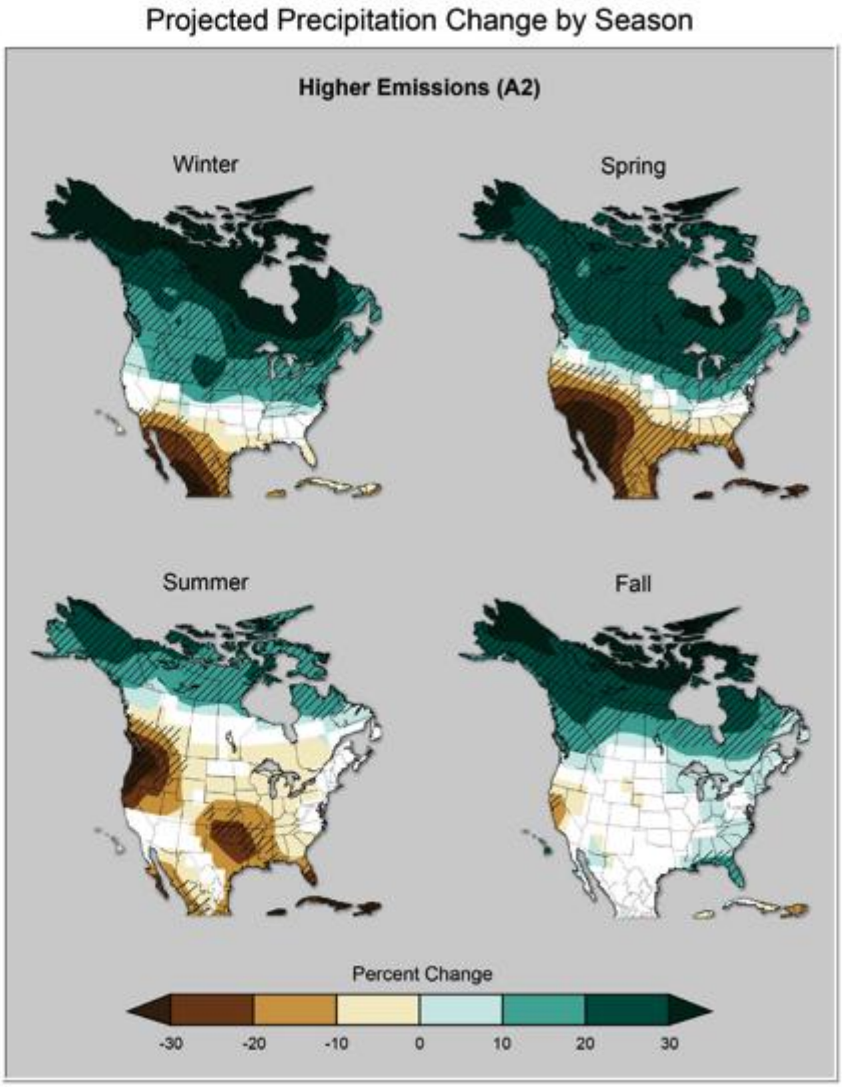


Figure 8: Projected percent change in seasonal precipitation for 2070-2099 (compared to the period 1901-1960) under the A2 emissions scenario. Teal indicates precipitation increases, and brown, decreases. Hatched areas indicate confidence that the projected changes are large and are consistently wetter or drier. White areas indicate confidence that the changes are small. (Figure source: NOAA NCDC / CICS-NC. Data from CMIP3; analyzed by Michael Wehner, LBNL)[21]

Though this scenario projects less total annual precipitation, a warmer atmosphere nonetheless has the capacity to hold more water vapor. This means that even while annual precipitation totals decrease, the rate at which precipitation falls may increase, leading to more intense rain or snow events, as well as potentially shorter return periods of heavy precipitation.

Heavy precipitation events are projected to occur more frequently everywhere in the U.S. For example, as seen in Figure 9, extreme daily precipitation events, under a scenario of relatively low greenhouse gas emissions, are projected to double in southern California by the end of this century (shown on the map to the left). Under a higher emissions scenario (as shown on the right) that same region could see the frequency of such events triple.

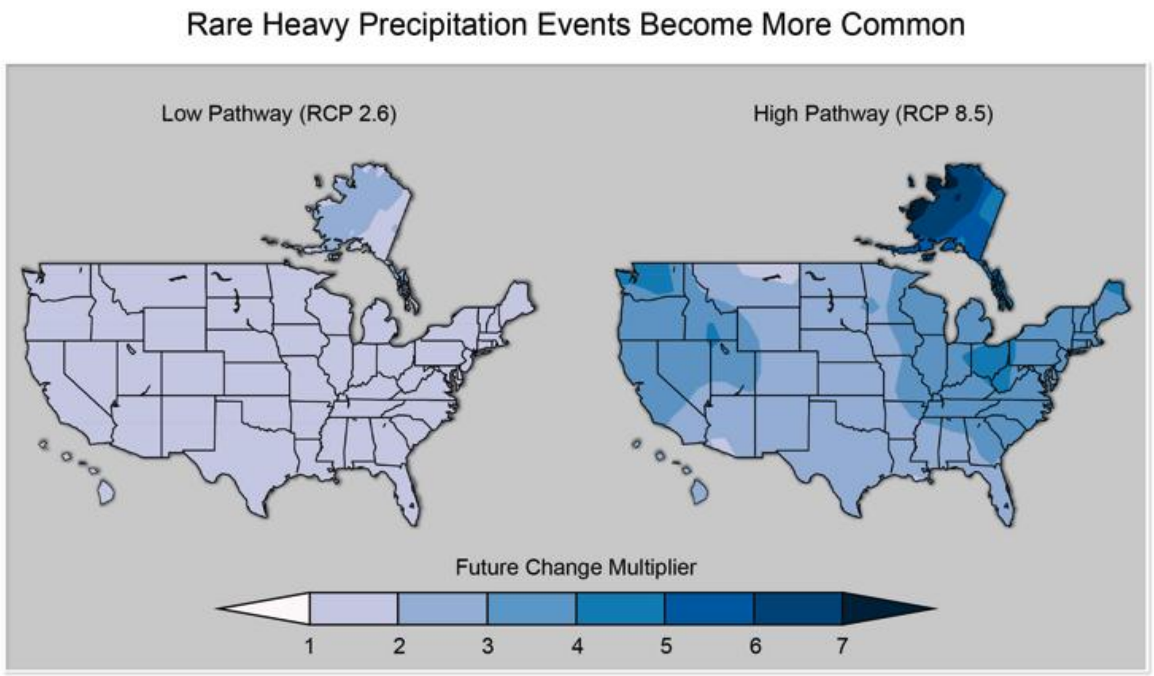


Figure 9: The increase in frequency of extreme daily precipitation events (now occurring about once every twenty years) by the later part of this century (2081-2100) compared to later part of last century (1981-2000). (Figure source: NOAA NCDC / CICS-NC. Data from CMIP5; analysis by Michael Wehner, LBNL; based on methods from (Kharin et al. submitted)[22]

3.2.2. Higher sea level and higher wave surge

Scenario headline messages:

- Sea level rise increases coastal erosion, flooding, and inundation.
- Sea level rise worsens impacts of El Niño events, high tides, and storms.
- Tidal wetlands and beaches accrete vertically, migrate landward, or become inundated with higher sea levels.

	2030	2050	2070	2100
sea level rise*	+ 7 in (+ 17.8 cm)	+ 14 in (+ 35.6 cm)	+ 24 in (+ 61.0 cm)	+ 48 in (+ 122.0 cm)

*Not including high tide or storm events, using 2000 as baseline year[23]

The implications of sea level rise for coastal California cannot be understood in isolation from other, shorter-term sea-level variability related to El Niño-Southern Oscillation (ENSO) events, storms, or extreme tides that affect the coast. Historically, the greatest damage to coastal areas has occurred during large El Niño events (for example in 1940–41, 1982–83, and 1997–98) when short-term sea-level increases occurred simultaneously with high tides and large waves. The example in Figure 10 is for San Francisco and similar variations would be expected for San Diego. In this figure, El Niño events raise sea level height by approximately one foot, on top of the existing sea-level rise that has increased about 8 in (~ 20 cm) along the California coast since 1900. As sea-level continues to rise,

the impacts of future large ENSO events will be greater than those historical events of similar magnitude, possibly exposing coastal areas to the combined effects of sea-level rise, elevated sea levels from El Niño events, high tides and large waves from storms.

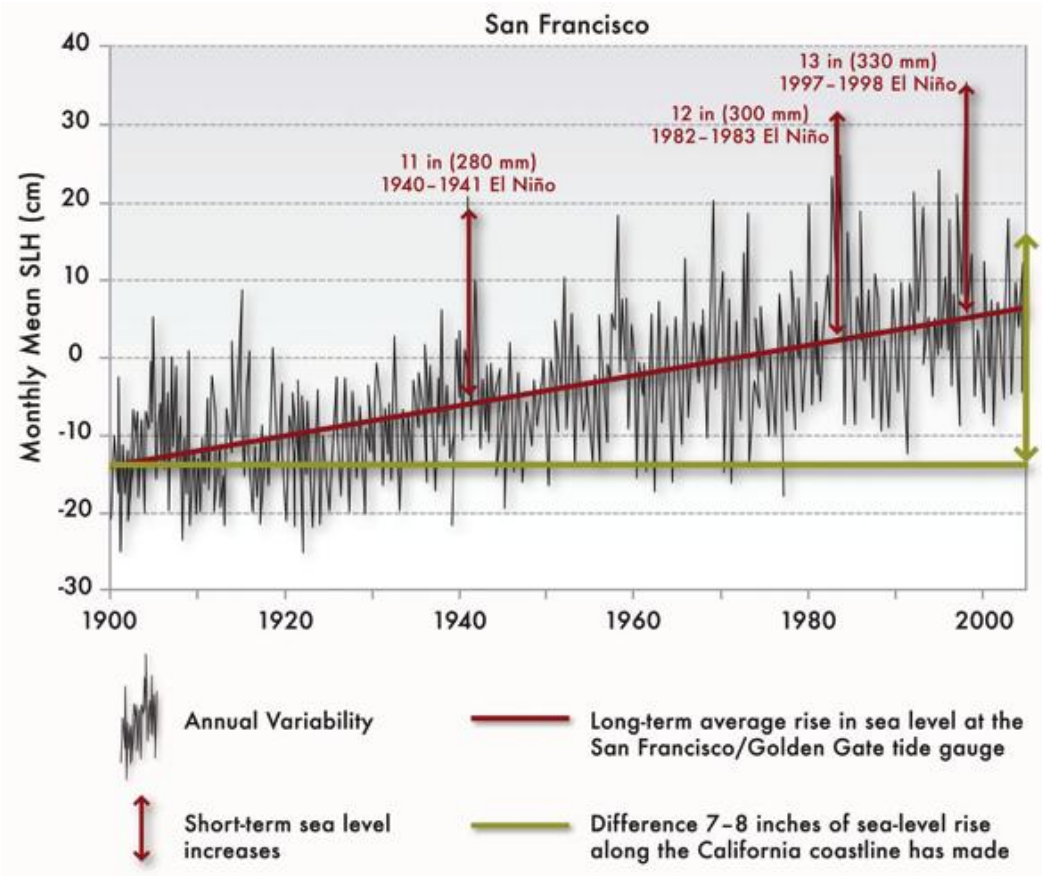


Figure 10: Sea-level rise and El Niño events[24]. (Data source: Pacific Decadal Oscillation monthly values index (http://jisao.washington.edu/pdo/), NOAA Earth System Research Laboratory Multivariate ENSO Index (http://www.esrl.noaa.gov/psd/enso/mei/#ref_wt3), Wolter and Timlin, (2011)).

To further compound the problem, any increased intensity and/or increased frequency of storm events will further aggravate the expected impacts from global sea-level rise, changing shorelines, near-shore ecosystems, and runoff. Storm events are inherently hard to model, due to the complexities of the coupled ocean-atmosphere system, leading to medium-low confidence in the trend towards increased intensity and frequency of storm events[25]. However, there is medium-high confidence that storms coupled with rising sea levels will increase the exposure to waves and storm surges[iii] for many regions along the coast.

[iii] An abnormal rise of water generated by a storm's winds. Storm surge can reach heights well over 20 feet and can span hundreds of miles of coastline (from NOAA National Hurricane Center).

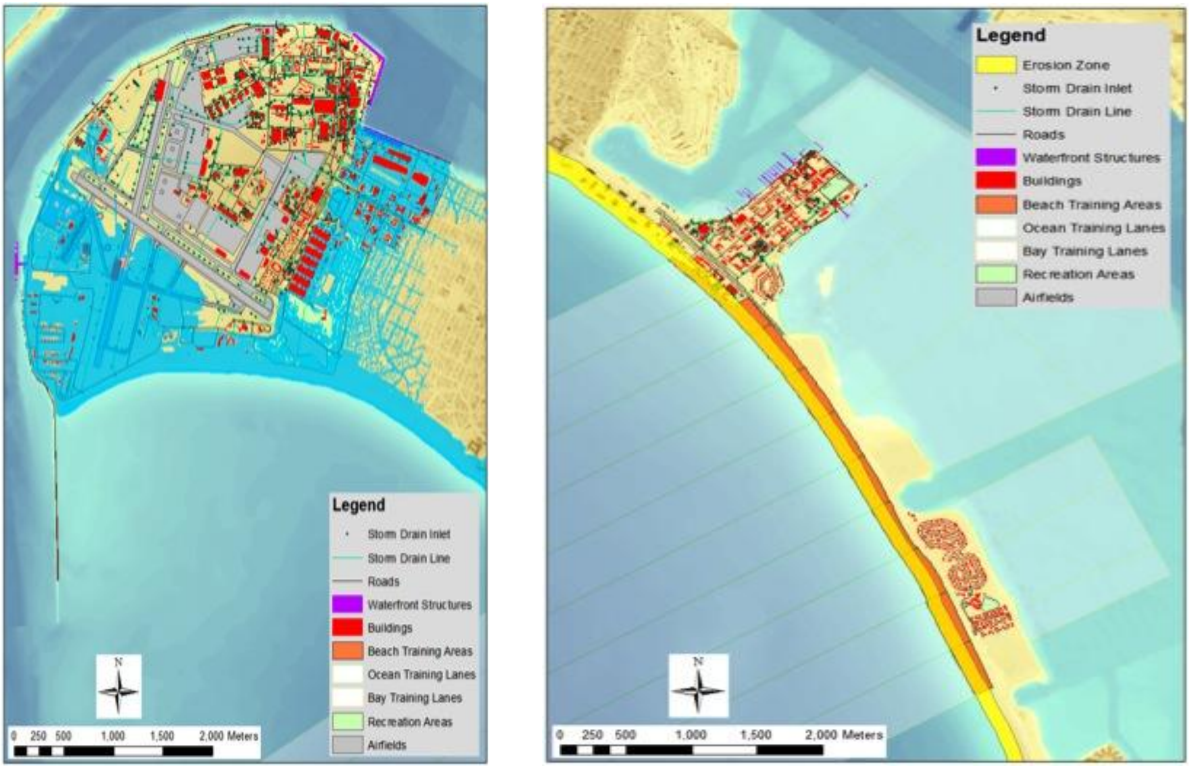


Figure 11 Left: flooding: Naval Air Station North Island (NASNI) – 1m SLR, 100-yr storm. Right: erosion: Naval Amphibious Base (NAB) – 1m SLR, 100-yr waves[26].

Increasing coastal inundation will have material impacts on NBC's infrastructure and facilities. Figure 11 visualizes potential coastal impacts with sea level rise for NASNI and the NAB. Under the conditions of 1 meter of sea level rise and a 100-year storm (left panel), potentially flooded areas on North Island are shown in blue, while infrastructure depicted on the map includes buildings in red and airfields in gray. Under the conditions of 1 meter of sea level rise and 100-year waves (right panel), areas of erosion at the Naval Amphibious Base are shown in yellow. For infrastructure, buildings are once again depicted in red, and beach training areas are in orange.

In the face of such coastal hazards, some of the southern Californian coast is armored. Coastal "hardening" can impede the natural movement and migration of beach areas and coastal wetlands by occupying or enclosing space into which migration would otherwise have occurred.

4. Climate change risk assessment methodology

4.1. Introduction: Risk-based framework

The approach piloted at NBC follows a framework for decision-making on climate change, applying guidance published in the UK by the UK Climate Impacts Programme (UKCIP) and the UK's Environment Agency (EA) (Figure 1 and Appendix 1)[27]. This is a useful framework because it is flexible in allowing the climate-related risks for DoD to be assessed across a wide variety of installations, operations and environments.

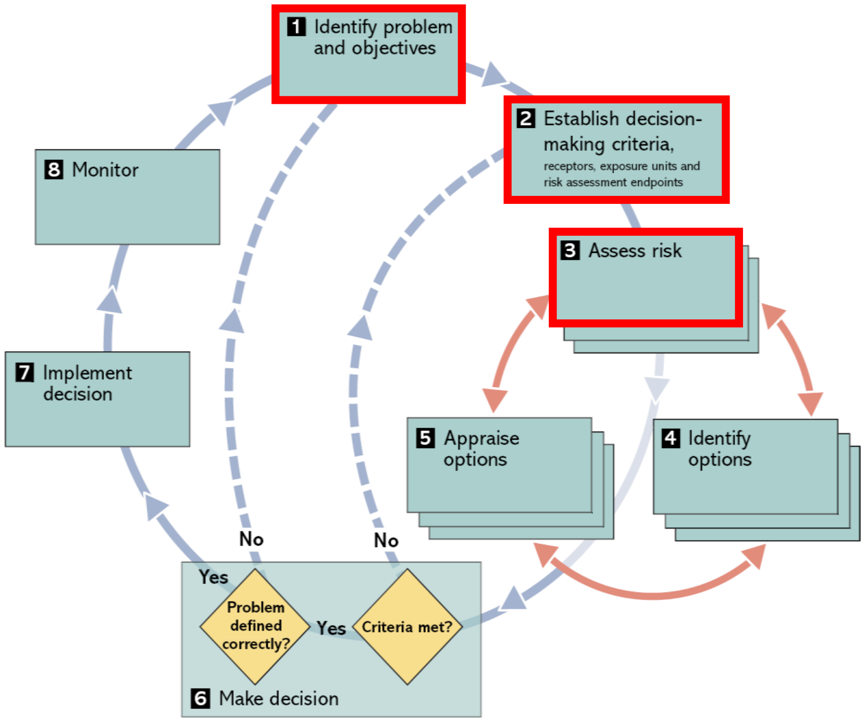


Figure 12: Risk assessment framework and approach[27]. The red border around boxes 1-3 highlight that this risk assessment focuses predominantly on these three steps of the framework process.

4.2. Data collection

Emphasis has been placed on undertaking the risk assessment in consultation with NBC personnel and stakeholders. A climate change adaptation workshop was held at NBC on 7 May 2013, focused on identifying key climate risks and opportunities for NBC, discussing how existing risks are managed and how they may change in the future. (The full agenda, list of participants and a workshop summary is provided in Appendix 2). This event provided very rich information and forms the basis of this report. The risks identified at the workshop have been supplemented by the research team's expert knowledge and previous experiences in a military context.

4.3. Risk assessment and prioritization

It is important that the mechanics of the risk assessment process draws on existing risk management methodologies used by the DoD or Navy. This will ensure that the process is familiar to NBC staff and that the outputs can be easily integrated into existing threats, hazards and consequences registers. Consequently, the evaluation of climate risks for NBC utilizes the Navy Installation Emergency Management Program Manual (CNI 3440.17), Standard 4 (hereafter referred to as 'The Manual'). A copy is included in Appendix 3.

The Manual recognizes that *"Emergency Management planning must be predicated on critical asset, threat/hazard, vulnerability, consequence, and response capability assessments. These assessments*

are used to evaluate an installation's ability to respond to a threat/hazard, protect the population on the installation and implement future strategies to mitigate risks"[28].

Risk is defined in The Manual as being: *"a function of threats/hazards, vulnerability to threats/hazards, and resulting consequences if these threats/hazards were to strike a critical infrastructure on an installation".* The following equation is used to provide a quantitative assessment of the relative risks posed:

$$\text{Risk} = \text{Critical Infrastructure (CI)} \times [\text{Threat (T) or Hazard (H)}] \times \text{Vulnerability (V)} \times \frac{\text{Consequence (C)}}{\text{Response Capability (RC)}}$$

Each of the components of this equation are discussed in more detail in Sections 4.3.2 to 4.3.6, including the assumptions made during its application to this climate change risk assessment.

An overarching assumption worth highlighting is that risks have been rated assuming that no additional adaptation measures are in place to address climate change (i.e. the green line in Figure 13) – rather than rating risks post-adaptation (red line in Figure 13). This will allow NBC to consider how significant the risks of climate change could be, if no adaptation action is taken.

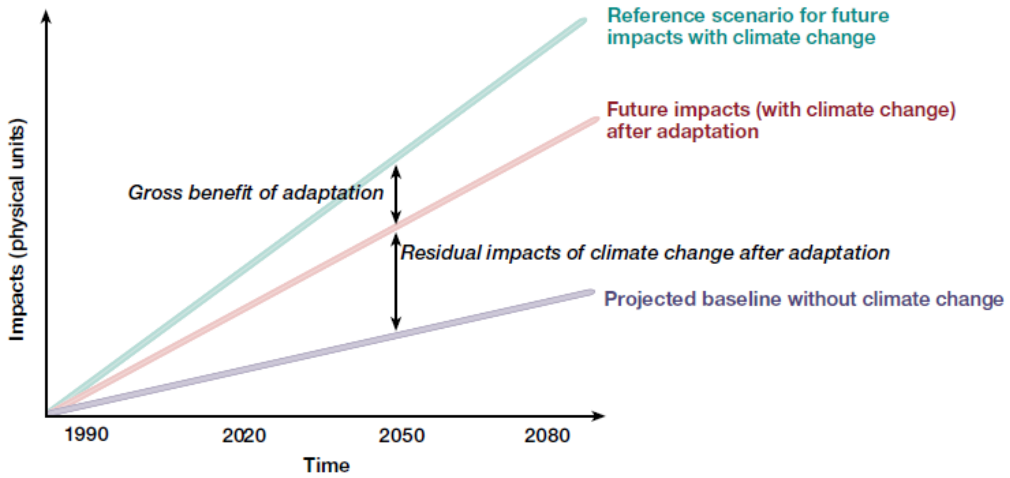


Figure 13: Illustration of climate change risks in absence of adaptation (difference between green line and blue line) and residual risks post-adaptation (difference between red line and blue line)[29].

4.3.1. Risk causal narrative

To provide consistency of description, risk causal narratives have been developed which clearly outline the "cause", "process" and "consequence". An example is provided in Table 4.

Table 4: Example risk causal narrative.

Risk ref no[iv].	Causal narrative		
	Cause (climate driver)	Process	Consequence
F12	More frequent heavy downpours of rain	causes flooding of underground infrastructure	with the consequence that critical IT, power and water supply may be affected

[iv] Risk reference codes relate to the workshop break-out groups, where the risk was originally identified: O = Operations; F = Facilities; T = Training; and EN = Environment.

In cases where climate drivers were unspecified and simply termed *"climate change"* or *"global warming"*, the standardized term *"incremental climate change"* has been used in this report to describe the slow, 'creeping' manifestations of longer-term climate change (e.g. increase in temperatures over several decades, sea-level rise). This term has also been used in cases where specifying the exact climate drivers are particularly challenging (e.g. factors that determine outbreaks of vector-borne and infectious diseases).

Conversely, the term *"extreme events"* has been used to describe acute climate variability, both over short and longer timescales. The Intergovernmental Panel on Climate Change (IPCC)[30] makes the distinction between extreme weather events and extreme climate events, although the distinction is not precise and the terms are often used interchangeably.

- An *extreme weather event* is typically associated with changing weather patterns, that is, within time frames of less than a day to a few weeks.
- An *extreme climate event* happens on longer time scales. It can be the accumulation of several (extreme or non-extreme) weather events (e.g., the accumulation of below average rainy days over a season leading to substantially below average cumulated rainfall and drought conditions).

Some climate extremes (e.g., droughts, floods) may be the result of an accumulation of moderate weather or climate events (this accumulation being itself extreme). Compound events, that is, two or more events occurring simultaneously, can lead to high impacts, even if the two single events are not extreme per se (only their combination). Finally, not all extreme weather and climate events have extreme impacts.

There is an increasing body of empirical evidence suggesting that extreme weather events have become more common in recent years, and the majority of scientists relate the increased frequency and intensity of such events to climate change. Looking forward, the recent IPCC report (2012) on extreme weather events judged it *"very likely that the length, frequency, and/or intensity of warm spells or heat waves will increase over most land areas"* and *"likely that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21st century over many areas of the globe"*[31].

The generally well-documented nature of extreme events has generated greater interest in planning for more severe and frequent climatic events. In contrast the 'creeping' average changes are much harder to recognize and are more likely to be overlooked. Consequently, this assessment has sought to identify the risks associated with both incremental changes and extreme events and the terminology used in the risk causal narratives highlights this distinction.

4.3.2. Critical infrastructure (CI) value

Using the guidance provided in The Manual, NBC is an operational base and therefore all risks were assigned a critical infrastructure value of 2. Because this risk assessment has been undertaken at a strategic / installation-wide scale (rather than individual asset-scale), the critical infrastructure value has been standardized across all risks.

4.3.3. Threat (T) or hazard (H) probabilities

As shown in Table 4-5 of The Manual (see Appendix 3), the hazard assessment criteria is composed of two elements: Hazard Relative Probability (Values) and Onset Values.

Each of the climate drivers were assigned a Hazard Relative Probability score, as outlined in Table 5. For the Onset Values, each individual risk causal narrative was reviewed and the definitions outlined in The Manual were applied unchanged.

Table 5: Hazard Relative Probability score for each of the climate drivers assessed

Relative ranking	Climate driver	Hazard Relative Probability	Reasoning
1	Incremental climate change	10	Based on observed climate data over the past few decades, warming of the climate system is unequivocal[32]. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased[33]. There is high confidence and high certainty that these trends will continue over the next few decades, irrespective of efforts to reduce greenhouse gas emissions, due to inertia in the climate system.
2	Sea Level Rise	10	There is high confidence and high certainty.
3	Extreme high temperatures	10	There is high confidence and high certainty.
4	Warmer and drier	2	Warmer is very certain, but drier (less precipitation) is less certain. Some of the uncertainty regarding precipitation is due to natural year-to-year and decade-to-decade variations.
5	Extreme events	1	There is moderate confidence and certainty that the frequency and intensity of extreme events will increase. There is great certainty regarding heat waves, than uncharacteristic precipitation-related events (e.g. droughts, El Niño rains).
6	More frequent heavy downpours	1	Currently, there is no trend in this statistic.
7	Sea level rise and higher wave surge	0.5	Sea level rise is very likely, but future higher wave surge is unknown because future changes in storm intensity are highly uncertain and the science of modeling wave surge from coarse-scale (i.e., modeled storm system) data is not refined enough for looking at the spatial scale of the NBC beachfront.

4.3.4. Vulnerability (V) value

As defined in The Manual, critical asset vulnerability values for natural hazards are assessed based on the following criteria:

- Compliance with building construction codes and HAZMAT Storage/Handing codes;
- Sheltering-in-Place, Evacuation Plans, Mass Notification System; and
- EM Awareness Training.

In this assessment, each individual risk causal narrative was reviewed and the definitions outlined in The Manual were applied unchanged, based on our team's professional judgment[v]. It was assumed that compliance with health & safety and environmental regulation will be particularly stringent and as such, risks containing these elements were typically given a low vulnerability value.

4.3.5. Consequence (C) value

The consequence value is based on a sum of the following criteria (each of which has a 5-point scoring scale):

[v] We intend to glean feedback from NBC personnel and stakeholders to validate our team's independent assessment.

- Installation Death or Injury;
- Installation/Asset Infrastructure (includes environmental remediation by EPA); and
- Asset Mission Capability.

In this assessment, each individual risk causal narrative was reviewed and the definitions outlined in The Manual were applied unchanged, based on our team's professional judgment[v].

4.3.6. Response capability (RC) value

Using the guidance provided in The Manual, NBC's existing response capabilities are Group 1, therefore all risks were assigned a response capability value of 8 (as the factor under consideration is a Natural Hazard).

5. Climate-related risks and opportunities for NBC

5.1. Introduction

The risks identified as a result of existing or projected climate variability and change, in the absence of further adaptation action, have been assessed and ranked (Table 6 in Appendix 4).

The key climatic changes (hazards) relevant to NBC are:

- Wildfires caused by warmer and drier conditions;
- Flooding and associated erosion due to more frequent heavy downpours of rain;
- Extreme high temperatures;
- Water scarcity caused by decreased precipitation; and
- Enhanced flooding caused by sea level rise, increased wave heights and storm surge.

These climatic changes, and the "top" 7 risks they pose to NBC, are expanded in more detail below and cover the spectrum of NBC's success criteria (as outlined in Section 2.3). The full suite of risks is discussed more broadly in the remainder of this chapter and presented in a risk register in Appendix 4. As outlined in Section 1.2, this risk assessment is high-level, i.e. at the installation-wide scale, and does not go to the level of detail of individual installations within NBC. However, risks and opportunities have been linked to specific NBC environments (coastal or inland), where relevant, or labeled as cross-cutting in the risk register (Appendix 4).

Sections 5.4 to 5.7 explore direct climate impacts to:

- Mission Essential Infrastructure, Assets and Services (Section 5.4);
- Force Protection and Safety (Section 5.5);
- Environment and Regulatory Requirements (Section 5.6); and
- Local Communities and Public Relations (Section 5.7).

These direct impacts frequently have cascading consequences for NBC's success criteria (as depicted in Figure 14) and Sections 5.8 and 5.9 explore these interconnections and end-point consequences to: Training and Operational Readiness (Section 5.8); and Emergency Preparedness (Section 5.9).

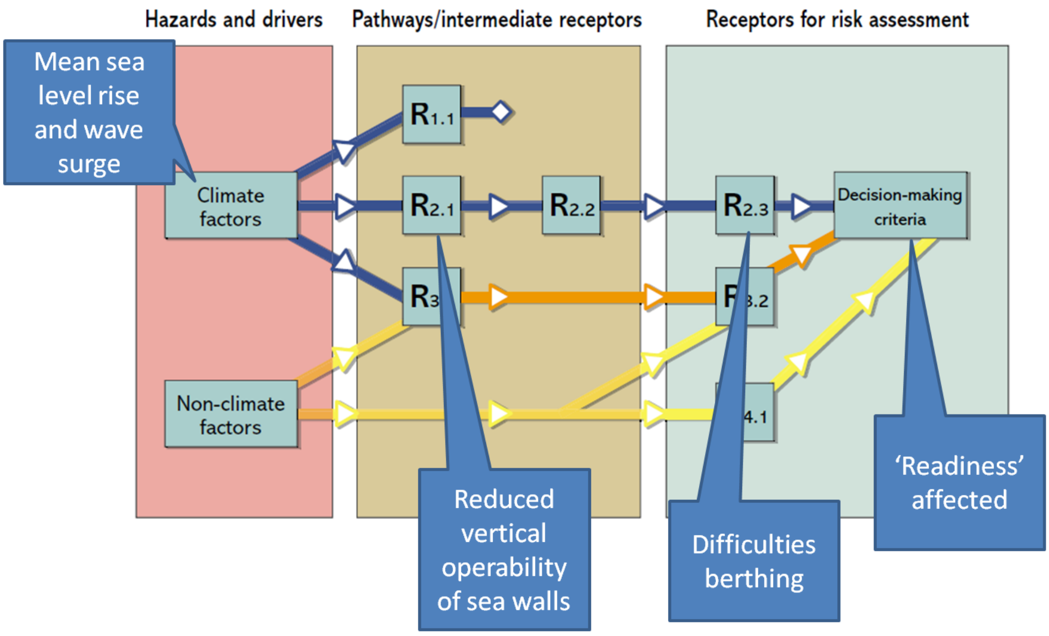


Figure 14: The pathway linking hazards (climate and non-climate factors), receptors and decision criteria[36]. A worked example for NBC is shown in the blue boxes.

5.2. "Top" risks

The "top" climate-related risks for NBC are outlined below, which result from a range of climate hazards and cover the spectrum of NBC's success criteria (as outlined in Section 2.3):

- Increased competition for resources may result in restricted access to supplies for NBC and potential conflict with other local users (risk ref. F06);
- Changes in the use and availability of land may restrict NBC's training mission, with consequences for operational readiness (risk ref. T02 / T14);
- Increasing NBC's resilience to incremental climate change and extreme events will result in increased capital, operational and maintenance expenditure and planned budgets may be exceeded (risk ref. T25 / F04);
- Increased risk of wildfires that damage / destroy remote training grounds and buildings, and cause wider natural environmental and hydrologic damage (risk ref. F03);
- Asset and equipment underperformance due to overheating and insufficient cooling, leading to loss of mission essential services (e.g. IT, power and communications) and operational readiness (risk ref. OP07 / F15 / F02 / F09);
- Erosion of inland sites due to more frequent heavy downpours of rain, causing environmental degradation and risk of further ground instability, especially following severe wildfires (risk ref. F26);
- Increased risk of adverse effects to air and water quality due to wild-fires, with associated impacts for human health and social functioning (risk ref. EN05 / EN10);
- Flooding and erosion of transportation routes due to more frequent heavy downpours of rain resulting in disruption to training and operations, and comprised emergency response (risk ref. F27 / OP21);
- Aircraft underperformance due to overheating with the loss of training and operational readiness (risk ref. OP05); and
- Heat stress for personnel due to more frequent extreme high temperatures, leading to increased rotation and loss of training time (risk ref. OP12).

5.3. Opportunities

A number of climate-related opportunities were highlighted in this assessment. They relate to the opportunities for NBC to raise its profile as a leader on adaptation, work collaboratively with others in the San Diego area and reduce vulnerability to the risk posed by climate change, as detailed below:

- NBC has the opportunity to position itself as a leader on the issue of adaptation to physical climate change by setting appropriate benchmarks and frameworks (risk ref. EN31);
- NBC has the opportunity to work more closely with local administrations and communities to improve the climate-resilience of the San Diego area (risk ref. EN23; T16); and
- NBC can mitigate the risks posed by a changing climate, by introducing necessary adaptation measures (e.g. water harvesting; risk ref. EN13) based on an improved understanding of the relationship between asset performance and environmental conditions.

5.4. Direct climate impacts to Mission Essential Infrastructure, Assets and Services

5.4.1. Introduction

Climate change (e.g. higher temperatures, changes in rainfall patterns and more intense and frequent extreme weather events) is likely to create a number of technical risks for NBC's existing infrastructure and essential services (e.g. energy, ICT, transport, water and wastewater). Infrastructure could be damaged or underperform because design criteria are based on a historical climate that are not necessarily applicable in a future changing climate. Individual assets may not be resilient to a broader range of climatic conditions, and normal asset wear and tear is likely to increase, with associated increases in repair and maintenance costs (as discussed in Sections 5.4.2 and 5.4.3). There is also the potential that asset lifespans will be shortened, with associated capital costs for replacement or modification. Third-party infrastructure on which NBC depends (e.g. energy, water, ICT and transport) will also be impacted by climate change, causing operational and logistical challenges (as discussed in Section 5.4.4). Discussion of the main climate-related risks to mission essential infrastructure, assets and services for each of these topics is divided by the five primary climate hazards outlined in Section 5.1.

5.4.2. Asset integrity and / or requirement for modifications

For a range of assets, integrity is likely to be impacted by climate change over time, with an increased requirement for modifications and retro-fitting, which has associated financial implications (risk ref. FO4). However, before the direct physical risks are described an important cross-cutting issue is worth highlighting: insurance[vi]. As present-day fixed asset damage cost increase, the spatial mapping of land at risk becomes more sophisticated and awareness of weather- and climate-related impacts increases, insurance companies are re-assessing the policies they offer (risk ref. OP40)[vii]. Over time, the consequence could be that insurance premiums increase, some assets become un-insurable and NBC takes on extra risk and financial burdens due to reduced cover.

5.4.2.1. Wildfires

In the most severe events, wildfires have the potential to cause extensive and irreversible damage to assets and infrastructure. Wider geographical distribution and increased frequency of wildfires as temperatures rise pose a threat to NBC's operations and assets in regions already susceptible or vulnerable to this hazard (e.g. Camp Michael Monsoor (CMM) Mountain Warfare Training Facility, San Clemente Island, Remote Training Site at Warner Springs (SERE) and Camp Morena). Direct damage to assets, whether through destruction or increased requirement for cleaning following ingress of carbon particles, has the potential to cause significant capital and operational expenditure costs, together with cascading consequences for operational and training readiness due to downtime (risk ref. FO3; FO2; OP2).

Case study 1: Wildfires in October 2007 (and 2003)

The October 2007 California wildfires were a series of fires that began burning across Southern California on October 20. At least 1,500 homes were destroyed and over 500,000 acres of land burned from Santa Barbara County to the U.S.–Mexico border. Of all the fires, the two biggest were located in San Diego County. The largest, the Witch (Creek) Fire, burned areas north and northeast of San Diego. The second largest, the Harris Fire, burned northwest from the U.S–Mexico border towards San Diego.

[vi] We are consulting NBC regarding insurance provision, so this text is likely to change in subsequent revisions.
[vii] There is evidence of this happening in other sectors (e.g. oil and gas). As above, we are in discussion with NBC as to whether this also applies in a military context.

NBC staff recalled the impacts of these wildfires, including:

- Navy staff death;
- staff sent home;
- operations stopped;
- destruction of endangered species habitat;
- soil erosion and sedimentation build-up in estuary;
- classed as an emergency and fire prevention gains made;
- NBC provided shelter for local communities; and
- Fleet ships transitioned off shore power to relieve electrical grid.

5.4.2.2. Flooding

Fluvial flooding has the potential to cause significant damage to infrastructure, assets and the surrounding environment, which will result in operational downtime and ultimately, a requirement for additional capital expenditure. Flooding, from rivers and estuaries, and surface water sources, can occur due to incremental changes in climate (e.g. progressive melting of land-based snow and ice raising global sea levels) or through extreme weather events (e.g. intense storms and exceedance of infrastructure drainage capacity). In extreme cases, flood events can cause significant erosion and slope failures (risk ref. OP09). Bank erosion on the Tijuana estuary side of the NOLF is noted as already threatening the landing platforms. NBC is also vulnerable to cross-border dumping of waste, compounding the impacts of extreme rainfall by causing localized restrictions in flow, elevating river levels and redirecting flow.

The majority of the flood-related risks identified at the workshop related to surface water flooding. This is generally a more complex problem than fluvial flooding and more difficult to predict, as the location and extent of flooding depends on heaviness and duration of rainfall, as well as the robustness of drainage systems. As a result, warning lead times tend to be much shorter. Assets and locations particularly at risk from surface water flooding include:

- large areas of hard standing (e.g. roads and airfields; risk ref. OP20; OP11),
- underground infrastructure (e.g. energy, IT and wastewater systems, lift stations; risk ref. F10; F12; OP19), and
- areas with storm water systems that are not designed to manage short duration intense rainstorms (e.g. beachfront car-park at the Silver Strand Training Complex; risk ref. (FO1; F24).

The consequences for NBC are that assets and infrastructure may be damaged or rendered temporarily inoperable, which has cascading consequence for operational and training readiness (risk ref. F25; T03). This risk is further compounded by a lack of baseline knowledge or maps of the underground cabling routes, which increases the installation's vulnerability to flood-related risks, from river, surface water and groundwater (risk ref. F16).

5.4.2.3. Sea level rise, coastal flooding and saline intrusions

Flooding of coastal assets can result from a number of mechanisms, including:

- incremental increase in mean sea level, due to the thermal expansion of sea water, melting of land-based snow and ice and changes in ocean circulation patterns;
- increased wave heights, due to storm activity and wind fetch; and
- storm surge processes, resulting from the development of intense low pressure systems offshore.

NBC's location makes coastal flooding particularly relevant. Any damage to assets and the surrounding environment is likely to result in operational downtime and ultimately, the requirement for additional capital expenditure, whether that is for maintenance or replacement (risk ref. OP27; EN26), or costs associated with coastal protection (e.g. replenishment; risk ref. OP25). To increase the protection of NBC's coastal infrastructure and assets or to relocate the facilities inland would involve significant capital costs. Flooding of coastal assets and infrastructure has the potential to render them inoperable. For example, increased stress on the vertical operability of quays may create challenges for the loading and unloading of ships (risk ref. F37) and flooding of power systems may create supply failures (risk ref. F30; F31). Saline floodwater typically causes more damage than freshwater flooding, due its corrosive nature. Infrastructure and asset types identified as being particularly at risk from coastal flooding include:

- Critical infrastructure (e.g. Emergency Operations Centre) (risk ref. F35)
- Transport (e.g. roads on the Silver Strand) (risk ref. OP36; OP25)
- Water supply and wastewater (risk ref. OP32; F35)
- Operational runways and landing lights (risk ref. EN20; F36)
- Piers, harbors, sea walls and berthing areas (risk ref. OP26; OP27; EN26; F38)
- Underground infrastructure (e.g. power sub-stations) (risk ref. F30; F31)

Moreover, sea level rise and higher wave surge have the potential to create saline intrusions, whereby the groundwater level rises and becomes increasingly saline. This may affect the integrity of submerged concrete structures and piles, and particularly those that have reinforced steel (risk ref. F33) and may result in critical buildings being at operational risk (e.g. Fleet Area FLATSFAC communication building; risk ref. F34).

5.4.2.4. Extreme high temperatures

Long periods of intense heat or drought can lead to soil settling effects beneath key structures and roads. More extreme temperatures alone can accelerate road deterioration; for instance, roads made from a bituminous hot mix are susceptible to "bleeding" in high temperatures, a process whereby the bitumen seeps through the aggregate to the road surface. This risk may affect asphalt runways shoulders and roads at NBC, which will render them inoperable and affect training and operational readiness (risk ref. F21). Temperature stress can cause lateral buckling on surface pipelines and other linear infrastructure, such as rail. Although often limited in extent, this can lead to operational disruption.

5.4.3. Asset performance

For existing, un-adapted assets, climate change is likely to reduce the efficiencies of assets and thus cause disruption to operations. Additional capital expenditure may also be required to modify existing assets so that they can cope with new climatic conditions.

5.4.3.1. Extreme high temperatures

Increased air temperature is widely known to cause decreased efficiency (and potential failure) of power generating, air-conditioning, process and electrical equipment (e.g. turbines, fin-fans, transformers and switches) (risk ref. F02; OP07; F15; F09) and aircraft (risk ref. OP05). This underperformance of assets will ultimately mean the downtime in equipment use and potential

power supply failures, which may lead to the requirement for asset modification and therefore capital expenditure.

Higher temperatures also have the potential to create additional demand for power and water, which the existing assets may not be able to provide effectively or efficiently. This will ultimately lead to increased operational costs (F05) and affect the provision of mission essential services (OP18).

5.4.4. Third party infrastructure and supply chains

Third-party infrastructure on which NBC depends (e.g. transport, energy, water, ICT) are likely to be impacted by climate change, causing operational and logistical challenges for the installation. A variety of climate hazards have the potential to cause damage and disruption to third-party infrastructure and their supply of services, including sea level rise and higher wave surge (risk ref. OP36; T21), warmer and drier conditions (risk ref. F13; F14; T05), more frequent extreme high temperatures (risk ref. OP08) and storm events (risk ref. F11).

In a future resource constrained world, NBC may face increased restrictions on energy and water use, due to the fact that NBC is a large user in the San Diego area. Under extreme conditions, for example power or water shortages, NBC's operations may be impacted (e.g. taking ships off the grid; risk ref. OP08; reducing water supply; risk ref. F13; F14; T05). This may lead NBC to invest in costly and energy-intensive alternatives, such as desalination plants (risk ref. F08).

NBC also relies on long supply chains and distribution networks, meaning that there is added indirect exposure to climate change impacts through their suppliers of goods and services. Climate-related risks include transport delays and interruptions, logistics and supply failures, and commodity price vulnerability (risk ref. F43). Supply chain visibility – namely, being able to map out and understand linkages and relationships – as well as cost containment, will become more difficult under continuing climate change.

5.5. Direct climate impacts to Force Protection and Safety

5.5.1. Introduction

There are a number of climate-related risks for force protection and safety which may change in the future, resulting from hazards including wildfires, extreme high temperatures, sea level rise and storm surge. These are grouped under the headings of installation perimeter and patrol (see Section 5.5.2), and personnel health and safety (see Section 5.5.3).

5.5.2. Installation perimeter and patrol

NBC has a controlled and secure perimeter, which is essential for force protection and anti-terrorism. Several climate hazards may cause protection and security issues, as outlined below.

5.5.2.1. Wildfires

These events may change the physical perimeter of the installation and cause patrol issues, through poor visibility, for example (risk ref. OP14).

5.5.2.2. Sea level rise and higher wave surge

Flooding and erosion associated with these hazards may cause difficulties in maintaining a perimeter around installations (risk ref. OP38), access problems to critical areas (risk ref. OP37), and over the longer term, an expansion of the in-water perimeter and patrol area (risk ref. OP39).

5.5.2.3. *Extreme high temperatures*

More frequent temperatures extremes have the potential to cause heat-stress related risks for military dogs, meaning that they are unable to perform their duties (risk ref. OP13).

5.5.3. Personnel health and safety

Climate change is unlikely to create any new personnel health and safety issues for NBC, but has the potential to increase the frequency of occurrence and severity of consequence. Generally, increased frequency and severity of extreme weather events may lead to critical safety thresholds being breached (risk ref. T11), an increased need for personnel training and capacity building (risk ref. T23) and changes in current warning systems and planning procedures (risk ref. T24; OP16). Specific risks are discussed in more detail below, divided by climate hazard.

5.5.3.1. *Wildfires*

Wildfires have the potential to have devastating consequences, including fatalities in the most severe events (risk ref. F23). Furthermore, air pollution associated with fires can pose a significant threat to human health and social functioning (risk ref. EN05; EN10; T09; OP15).

5.5.3.2. *Flooding*

Floods have the potential to directly cause injuries and fatalities, through the movement of flood water and debris. Associated indirect consequences include contamination of water courses (e.g. Tijuana River runoff), which may affect health and safety through water quality issues (risk ref. OP17).

5.5.3.3. *Sea level rise, coastal flooding and storm surge*

Coastal flooding, where the lead-in times are short, for example due to storm events, have the potential to directly cause injuries and fatalities, and lead to increased evacuations and a shift to mission essential only personnel (risk ref. T22; T26). Coastal flooding also can mobilize contaminants in soil, posing a threat to personnel and civilian health and safety (risk ref. OP33).

5.5.3.4. *Extreme high temperatures*

More frequent extreme high temperatures have the potential to cause heat-stress related risks for personnel, which in extreme case can cause fatalities (risk ref. T31). To protect personnel against this risk, the Navy has strict policies regarding work / rest cycles (when temperatures rise above 90°F, 45 minutes rest for every 15 minutes work). If such high temperatures become more common under a changing climate, there is the potential that training time will be lost and there will be an increased rotation of personnel (risk ref. T10; OP10; OP12).

5.6. Direct climate impacts on the Environment and Regulatory Requirements

5.6.1. Introduction

NBC fully recognizes environmental stewardship is an integral part of productivity and providing quality services across the installation's activities[34]. In recognition of this responsibility to NBC's sailors, customers, civilian personnel, neighbors and others, NBC is committed to[34]:

- Being an environmentally responsible neighbor to ensure public health and safety and protection of the environment;
- Preserving significant aspects of the natural and cultural environment;
- Using sustainable resources to modernize facilities and shore-side infrastructure;
- Conserving natural resources by reducing, reusing, and recycling materials; and purchasing products made from recycled materials;

- Developing and improving operations and technologies that minimize waste; preventing air and water pollution; minimizing health and safety risks; and disposing of waste safely and responsibly;
- Ensuring the responsible use of energy and water, including conservation and improved efficiency;
- Sharing appropriate pollution prevention technologies, knowledge and methods;
- Participating in efforts to improve environmental protection and understanding in local communities;
- Adhering with applicable environmental federal, state, and local regulations, and Department of Defense, and Navy policies; and
- Ensuring their policy is communicated to all military and civilian personnel, and contractors to encourage continual improvement within the region.

Climate change has the potential to directly impact the local environment, with associated consequence for NBC's environmental stewardship and regulatory requirements (risk ref. EN15). For instance, incremental climate change could directly affect endangered species or cause changes in their behavior leading to their migration into or away from land owned and protected by NBC (risk ref. EN01; TO6). This has the potential to result in increased management costs for environmental compliance (risk ref. EN15), issues associated with insurance (risk ref. EN18) and potential legal challenges (risk ref. EN17). Discussion of the main climate-related impacts on the environment and regulatory requirements is divided by the primary climate hazards outlined in Section 5.1.

5.6.1.1. Wildfires

Wildfires have the potential to damage and destroy large areas of woodland and scrub vegetation. Under a changing climate, increased frequency and intensity of wildfires may result in habitats being significantly changed and / or lost, with the consequence that NBC's environmental management efforts escalate (risk ref. EN04).

5.6.1.2. Flooding

More frequent heavy downpours of rain have the potential to alter contaminant pathways, with pollutant run-off from land, properties or equipment into surface and ground water sources (risk ref. F22). Furthermore, changes in ground conditions (including subsidence, heave and landslips; risk ref. F26) could create new pathways for contaminants, which would then flush through into water courses during heavy rainfall (risk ref. EN02). Increased migration of contaminants may represent an additional compliance risk. The (re)mobilization of contaminants in fill, as well as unexploded ordnance (UXO), was expressed as being a current vulnerability, especially on the bayside of the NAB. Flooding of historic properties and archaeological sites may also create environmental management challenges for NBC, with additional resources being needed for cultural work (risk ref. EN14; EN03).

Case study 2: Winter storm December 2010

In December of 2010, California was impacted by a series of severe winter storms which damaged property and businesses – particularly in Southern parts of the state. In the span of one week, a series of mid-December storms in rapid succession discredited climate predictions of a drier-than-average La Niña winter in southern California, southern Nevada and much of the Southwest, producing in some cases record-setting rain and snowfall[35].

NBC staff recalled the impacts of this particularly severe storm, including:

- flooding of Tijuana River
- damage to pier and waterfront facilities
- loss of training days, in-water training stopped due to health concerns associated with river flooding
- loss of access to water for the recreational community
- transportation problems due to closed roads
- economic loss to the base due to flooding of agricultural fields
- clean up and repair exercise with associated economic impacts

5.6.1.3. Aridity

Warmer and drier conditions may cause changes in the local environment, including changes in soil moisture, vegetation cover and the distribution and numbers of non-native wildlife / invasive species (risk ref. EN11; EN08; EN07). These changes may be beneficial or detrimental to the environment, creating management opportunities or challenges for NBC.

5.6.1.4. Sea level rise, coastal flooding and storm surge

Sea level rise and higher wave surge may cause changes in the coastal and marine environment creating environmental management challenges and compliance issues for NBC (risk ref. EN30). This could be both positive (e.g. the restoration of wetlands, with associated impacts on water quality; risk ref. EN24) or negative (e.g. erosion of long shores; risk ref. T19). These changes will have associated consequences for the species living in these coastal habitats (e.g. Eel grass, nesting birds) (risk ref. EN21 / EN22 / T28). There is the potential that NBC may not be able to meet their obligations under the Endangered Species Act (risk ref. T17) and to the Coastal Commission (risk ref. T20).

Saline intrusion and changes in groundwater levels may also create new source-pathway-receptor relationships, increasing pollution risks associated with contaminated land (e.g. waste storage areas) (risk ref. EN28; EN29; OP34). Sea level rise and higher wave surge may also cause flooding and exceedance of storm water drainage systems, with the consequence that environmental regulatory compliance is compromised (risk ref. EN19).

Sea level rise and the flooding of coastal assets (discussed in more detail in Section 5.4.2.3) may also lead to an increase in regulatory activities (risk ref. EN27). For instance, discharge consents may be affected due to higher concentrations of pollutants in run-off (e.g. from roads and runways).

5.7. Direct climate impacts on Local Communities and Public Relations

5.7.1. Introduction

NBC is intimately connected to the local communities surrounding the installation and its operations can result in impacts, both positive and negative, in many ways. The benefits NBC aims to bring to local people include jobs, contracting and business opportunities and social investment.

Furthermore, NBC works hard to manage any negative effect on the livelihood, health, safety, lifestyle, security and economic development of local communities and maintain social licence to operate.

5.7.2. 'Beyond the fence-line' risks

Climate change is likely to impact San Diego and its people, and there are a number of 'beyond the fence-line' risks that will have implications for NBC's operations and reputation within the region. This can be both positive, if NBC is able to work more closely with local administrations and communities to improve the climate-resilience of the San Diego area (risk ref. EN23; T16), or negative, if NBC is viewed as being culpable for environmental degradation or takes risk management actions that are viewed as detrimental to the local area (risk ref. EN16). An example of the latter could be NBC not fulfilling beach nourishment requirements (risk ref. T18).

Key drivers including changes in water resource availability (risk ref. T04), changes in land use and space allocation (e.g. due to sea level rise and coastal erosion; risk ref. T02; T14) and the migration of people due to natural disasters (risk ref. T01). The resulting consequence could be that NBC is required to further support neighboring communities and communicate more effectively, with additional resources allocated to public relations activities (risk ref. T15).

5.8. Cascading consequences for Training and Operational Readiness

5.8.1. Introduction

Of the risks discussed in Sections 5.4 to 5.7 above, a high proportion have interconnections and cascading consequences for NBC's primary and overarching success criteria, namely training and operational readiness. These are explored in more detail below, again divided by primary climate hazard. On a general note, a changing climate (both incremental climate change and extreme events) has the potential to make the civilian population more risk averse, and as a consequence the number of tenants brought in may reduce and training days may be lost (risk ref. T13).

5.8.1.1. Wildfires

As described in Sections 5.4 to 5.7, wildfires have the potential to cause significant damage and disruption to assets, training grounds (e.g. Camp Michael Monsoor (CMM) Mountain Warfare Training Facility, San Clemente Island, Remote Training Site at Warner Springs (SERE) and Camp Morena), third party infrastructure (e.g. communication routes) and the wider natural environment, which will ultimately equate to a loss of training time and operational readiness (risk ref. F03; F20 / OP2; T12). This may be due to the direct loss of operating infrastructure and assets, diversion of resources to evacuation and fire fighting (risk ref. OP01), limits to ordnances (OP03) and restrictions to troop movements between installations / regions (risk ref. OP04).

5.8.1.2. Flooding

As discussed above, flood events and associated impacts on assets, facilities and transport routes can render assets inoperable and prevent staff access, therefore resulting in a loss of training time and operational readiness (risk ref. F27 / OP21; OP09; OP20 / OP11; F25 / TO3).

5.8.1.3. Sea level rise, coastal flooding and storm surge

Sea level rise and higher wave surge and the associated flooding and erosion (e.g. Silver Strand, Naval Outlying Landing Field, Imperial Beach) have the potential to make assets and utilities inoperable and / or damaged, which will ultimately affecting training and operational readiness (risk ref. OP24 / T27; T21; F29;). A specific example quoted at the workshop was flooding of Runway 36,

which affects aircraft operations, training and readiness (risk ref. F39). Equally flood-related damage and disruption to third party transport infrastructure (e.g. roads in the former Spanish Bight; Silver Strand Highway) will affect traffic and staff accessibility, and thus training time (risk ref. T29; F40). Environmental changes, particularly species migration (as described in section 5.6.1.4) may cause NBC to review current and ongoing operational and training activities (risk ref. EN21; OP28; OP06). Finally, on a larger scale, loss of land due to coastal inundation and erosion may mean that the development of new training and operational facilities is constrained and expansion of NBC's capacity is not realized (risk ref. F28).

5.8.1.4. Extreme high temperatures

As discussed in Section 5.5.3.4, more frequent extreme high temperatures may cause increased incidents of heat stress for personnel, with the consequence that training time is reduced due to compliance with work / rest cycle (when temperatures rise above 90°F, 45 minutes rest for every 15 minutes work) (risk ref. OP10). When multiplied by the number of personnel affected by this code of practice, this risk has the potential to significantly affect training time.

5.9. Cascading consequences for Emergency Preparedness

5.9.1. Introduction

On a similar note, several of the risks discussed in Sections 5.4 to 5.7 above have cascading consequence for NBC's emergency preparedness. These are explored in more detail below, under the heading of resource diversion.

5.9.2. Diversion of resources

Several climate hazards and their associated impacts have the potential to divert NBC's resources aware from mission objectives and training needs, including extreme events (e.g. flooding, sea level rise) (risk ref. OP23; OP31). Increased frequency and magnitude of such events under a changing climate may mean that costs associated with emergency preparedness increase (e.g. purchasing more equipment and conducting more frequent drills). Finally, due to the installation's size and expertise, surrounding communities may look to NBC for leadership and emergency response services (e.g. debris removal), which ultimately diverts staff time and resources away from training and operational tasks.

References

[1] Adger, N.W., Lorenzoni, I. and O'Brien, K.L. (2009). "Adaptation Now" in Adger, N.W., Lorenzoni, I. and O'Brien, K.L. (eds) (2009): Adapting to Climate Change: Thresholds, Values, Governance. Cambridge University Press: Cambridge.

[2] Eakin, H., Tompkins, E.L., Nelson, D.R. and Anderies, J.M. (2009). "Hidden Costs and Disparate Uncertainties: Tradeoffs in Approaches to Climate Policy" in Adger, N.W., Lorenzoni, I. and O'Brien, K.L. (eds) (2009): Adapting to Climate Change: Thresholds, Values, Governance. Cambridge University Press: Cambridge.

[3] Naval Facilities Engineering Command (2010). Naval Base Coronado Activity Overview Plan.

[4] NBC website (2013). http://www.cnic.navy.mil/regions/cnrsw/installations/navbase_coronado/about/installations.html (Accessed 20/10/13)

[5] NBC website (2013). http://www.cnic.navy.mil/regions/cnrsw/installations/navbase_coronado/about/mission_and_vision.html (Accessed 20/10/13)

[6] Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy, eds. (2013). Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment. A report by the Southwest Climate Alliance. Washington, DC: Island Press

[7] Walsh, J., Wuebbles, D., Hayhoe, K., Kunkel, K., Somerville, R., Stephens, G., Thorne, P., Vose, R., Wehner, M., Willis, J., Anderson, D., Kharin, V., Kossin, J., Knutson, T., Lenton, T., Kennedy, J. (2013). Chapter 2: Our Changing Climate. National Climate Assessment. (Draft for Public Comment, v. 11 Jan 2013).

[8] *Ibid*

[9] Hoerling, M. P., M. Dettinger, K. Wolter, J. Lukas, J. Eischeid, R. Nemani, B. Liebmann, and K. E. Kunkel. 2013. "Present Weather and Climate: Evolving Conditions." In Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 74–100. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

[10] Walsh, J., Wuebbles, D., Hayhoe, K., Kunkel, K., Somerville, R., Stephens, G., Thorne, P., Vose, R., Wehner, M., Willis, J., Anderson, D., Kharin, V., Kossin, J., Knutson, T., Lenton, T., Kennedy, J. (2013). Chapter 2: Our Changing Climate. National Climate Assessment. (Draft for Public Comment, v. 11 Jan 2013).

[11] *Ibid*

[12] *Ibid*

[13] Overpeck, J., G. Garfin, A. Jardine, D. E. Busch, D. Cayan, M. Dettinger, E. Fleishman, A. Gershunov, G. MacDonald, K. T. Redmond, W. R. Travis, and B. Udall. (2013). "Summary for Decision Makers." In Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 1–20. A report by the Southwest Climate Alliance. Washington, DC: Island Press

[14] Hoerling, M. P., M. Dettinger, K. Wolter, J. Lukas, J. Eischeid, R. Nemani, B. Liebmann, and K. E. Kunkel. 2013. "Present Weather and Climate: Evolving Conditions." In Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 74–100. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

[15] IPCC (2013). Scenario Process for AR5. http://sedac.ipcc-data.org/ddc/ar5_scenario_process/index.html

[16] Parris, A. et al., (2012). Global Sea Level Rise Scenarios for the United States National Climate Assessment. NOAA Technical Report OAR CPO-1. http://cpo.noaa.gov/sites/cpo/Reports/2012/NOAA_SLR_r3.pdf

[17] Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy, eds. (2013). Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment. A report by the Southwest Climate Alliance. Washington, DC: Island Press

[18] Nakićenović, N., J. Alcamo, G. Davis, B. de Vries, J. Fenhann, S. Gaffin, K. Gregory, A. Grübler, T.Y. Jung, T. Kram, E.L. La Rovere, L. Michaelis, S. Mori, T. Morita, W. Pepper, H. Pitcher, L. Price, K. Raihi, A. Roehrl, H.-H. Rogner, A. Sankovski, M. Schlesinger, P. Shukla, S. Smith, R. Swart, S. van Rooijen, N. Victor and Z. Dadi, (2000). Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, and New York, 599 pp.

[19] Cayan, D., M. Tyree, K. E. Kunkel, C. Castro, A. Gershunov, J. Barsugli, A. J. Ray, J. Overpeck, M. Anderson, J. Russell, B. Rajagopalan, I. Rangwala, and P. Duffy. 2013. "Future Climate: Projected Average." In Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 101–125. A report by the Southwest Climate Alliance. Washington, DC: Island Press.
[20] Kunkel, K.E, L.E. Stevens, S.E. Stevens, L. Sun, E. Janssen, D. Wuebbles, and J.G. Dobson, (2013). Regional Climate Trends and Scenarios for the U.S. National Climate Assessment. Part 9. Climate of the Contiguous United States, NOAA Technical Report NESDIS 142-9, 77 pp
[21] Walsh, J., Wuebbles, D., Hayhoe, K., Kunkel, K., Somerville, R., Stephens, G., Thorne, P., Vose, R., Wehner, M., Willis, J., Anderson, D., Kharin, V., Kossin, J., Knutson, T., Lenton, T., Kennedy, J. (2013). Chapter 2: Our Changing Climate. National Climate Assessment. (Draft for Public Comment, v. 11 Jan 2013).
[22] *Ibid*
[23] Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy, eds. (2013). Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment. A report by the Southwest Climate Alliance. Washington, DC: Island Press
[24] Caldwell, M. R., E. H. Hartge, L. C. Ewing, G. Griggs, R. P. Kelly, S. C. Moser, S. G. Newkirk, R. A. Smyth, and C. B. Woodson. 2013. "Coastal Issues." In Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 168–196. A report by the Southwest Climate Alliance. Washington, DC: Island Press.
[25] Caldwell, M. R., E. H. Hartge, L. C. Ewing, G. Griggs, R. P. Kelly, S. C. Moser, S. G. Newkirk, R. A. Smyth, and C. B. Woodson. 2013. "Coastal Issues." In Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 168–196. A report by the Southwest Climate Alliance. Washington, DC: Island Press.
[26] Chadwick, B. (2013). Personal communication.
[27] Willows, R.I. and Connell. R.K. (Eds). (2003). Climate adaptation: Risk, uncertainty and decision-making. UKCIP Technical Report. UKCIP. Oxford. Note: Connell. R.K. is Chief Technical Officer for Acclimatise.
[28] Navy Installation Emergency Management Program Manual (CNI 3440.17). 23 January 2006
[29] Metroeconomica, (2004). Costing the impacts of climate change in the UK: overview of guidelines. UKCIP Technical Report. UKCIP, Oxford
[30] IPCC (2012): Summary for Policymakers. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 1-19.
[31] *Ibid*
[32] IPCC (2013). Climate Change 2013. The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change Summary for Policymakers.
[33] *Ibid*
[34] NBC website (2013).
http://www.cnic.navy.mil/regions/cnrsw/installations/navbase_coronado/about/environmental.html (Accessed 25/10/13)
[35] NOAA (2013). Heavy Precipitation Event California and Nevada December 16 - 23, 2010. http://www.cnrfc.noaa.gov/storm_summaries/dec2010storms.php (Accessed 4/11/13)

Appendix 1: Overview of the risk assessment framework

In line with best practice in decision-making and policy-making, this assessment of changing climate risks for NBC has been developed using a risk-based approach. Its development has drawn on the UK Climate Impacts Programme (UKCIP) and Environment Agency (EA) risk-based climate adaptation decision-making framework[36] (Figure 12). The climate change risk assessment process trialed at NBC focuses on steps 1 to 3 of the framework only, as outlined below:

- **Step 1: Identify objectives**: This step involves understanding individual installations' objectives and establishing the reasons for the decision being made. This includes an understanding of the risks climate change poses, how important climate change is believed to be as a driver, where within the installations' operations climate change needs to be considered and who needs to be involved.

- **Step 2: Establish decision-making criteria**: This step involves defining the risk criteria, exposure units, thresholds, receptors and performance criteria, together with determining the process by which risks will be evaluated, how the results will be used, and identifying stakeholders who will be important in undertaking and/or being consulted about the risk assessment.

- **Step 3: Assess risks**: Climate risks are assessed, utilizing three central steps:
    - **Hazard identification.** This involves identification of primary climatic variables (e.g. sea level, temperature), as well as synoptic (e.g. storm tracks), compound (e.g. humidity or mist) and proxy (e.g. water run-off) variables that may represent hazards.
    - **Vulnerability and risk identification.** This step involves identifying the pathways that link hazards to risk receptors, including decision-making criteria identified at step 2 (Figure 15). Risk end-points are taken forward into the risk evaluation.
    - **Risk evaluation.** This involves analyzing the likelihood of occurrence and severity of consequence.

The steps outlined above formed the basis and structure of a one-day climate change workshop at NBC (the workshop agenda is included in Appendix 2). The risks identified by workshop participants during Step 3 were evaluated after the event by Acclimatise, utilizing the Navy Installation Emergency Management Program Manual (CNI 3440.17), Standard 4 (a copy is included in Appendix 3). In cases were comparable risks were identified several times (usually between different break-out groups), risks have been combined and rationalized to provide a shorter risk register. The original risk reference codes have been retained to enable identification of the risk source; this explains why some risks in the risk register have several risk reference codes.

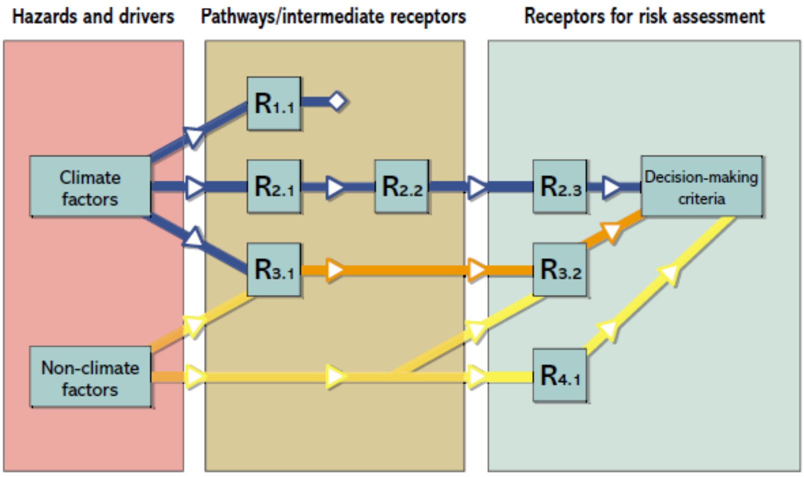


Figure 15: The pathway linking hazards (climate and non-climate factors), receptors and decision criteria[36].

[36] Willows, R.I. and Connell, R.K. (Eds.). (2003). Climate adaptation: Risk, uncertainty and decision-making. UKCIP Technical Report. UKCIP, Oxford. 154pp.

Appendix 2: Workshop agenda and summary

'Climate Change Impacts to Department of Defense Installations'

Naval Base Coronado, 7 May 2013

Introduction to this project

Climate change will affect Department of Defense (DoD) operations, DoD's stewardship responsibilities as well as its relationships with other agencies, the private sector and the local communities and environment within which it operates. The University of Arizona (UA), in partnership with Acclimatise (a UK-based climate change adaptation consultancy), is working on a project to support the DoD to integrate climate risk into their operational planning, asset management and strategic objectives.

Using Naval Base Coronado (NBC) as a case-study pilot, we are working in partnership with DoD managers and external agencies to develop robust approaches to climate change risk assessment and adaptation, all of which are supported by a set of climate adaptation tools that can be used across DoD operations.

Aims of this workshop

1. Identify and discuss key climate risks to NBC
2. Discuss how existing risks are managed and how these may change in the future
3. Identify the information gaps for adequately managing future risks
4. Start to identify information, models and tools needed by NBC to manage priority climate risks.

The workshop will be a mixture of plenary presentations and break-out group discussions. Your input is invaluable and fundamental to help guide and inform NBC and wider DoD thinking on the issue of climate change risks, and the information and tools required to support adaptation.

Timing	Title and content	Who
08:30 – 08:45	**Welcome**	NBC representative
08:45 – 09:15	**Session 1a: Introduction** • The aims and objectives of this project • Background to climate change • How climate change could affect DoD • Aims of workshop and guidance for breakout groups • Overview of topics covered in breakout groups	 • UA • UA • Acclimatise • Acclimatise • Acclimatise

09:15 – 09:45	**Session 1b: Warm-up exercise** • Observed weather-related impacts and emergency response at NBC.	Small group exercise
09:45 – 10:15	**Session 2: Overview of roles and responsibilities** • Description of group's primary roles, responsibility key objectives and success criteria.	Breakout groups
10:15 – 10:45 10:45 – 11:30	**Session 3: Exploring future scenarios** • Review existing and future climatic conditions for two scenarios • Briefing on identifying sensitivities and critical thresholds **Session 3a: Warmer and drier with occasional heavy rainfall** • Identify the risks to the performance of the base, including sensitivities and critical thresholds ('trigger points') • Prioritization of risks • (Note the risks that have cascading consequences for other groups)	• UA • Acclimatise • Breakout groups
11:30 – 11:45	**Break**	
11:45 – 12:30	**Session 3b: Higher sea level, higher wave surge** *(Structure as above)*	• Breakout groups
12:30 – 13:30	**Working Lunch: Compound and interconnected risks** • Name the risks that have cascading consequences for other groups	• All
13:30 – 14:00	**Session 4: Summary of morning session** • Voting on priority risks, to identify those most critical to NBC	• All
14:00 – 15:00	**Session 5: Exploring risk management** • Understanding how risks are currently managed, identifying information needs and other barriers as well as opportunities	• UA and breakout groups
15:00 – 15:15	**Break**	
15:15 – 15:45	**Session 6: Discussion of breakout group findings**	• UA and breakout groups
15:45 – 16:15	**Next Steps** – What can UA provide going forward?	• UA

‘Climate Change Impacts to Department of Defense Installations’
Naval Base Coronado, 7 May 2013

Workshop Summary

Introduction to this project

Climate change will affect Department of Defense (DoD) operations, DoD’s stewardship responsibilities as well as its relationships with other agencies, the private sector and the local communities and environment within which it operates. The University of Arizona (UA), in partnership with Acclimatise (a UK-based climate change adaptation consultancy), is working on a project to support the DoD to integrate climate risk into their operational planning, asset management and strategic objectives.

Using Naval Base Coronado (NBC) as a case-study pilot, we are working in partnership with DoD managers and external agencies to develop robust approaches to climate change risk assessment and adaptation, all of which are supported by a set of climate adaptation tools that can be used across DoD operations.

Workshop at NBC

Aims

The aims of the workshop were to:

1. Identify and discuss key climate risks to NBC
2. Discuss how existing risks are managed and how these may change in the future
3. Identify the information gaps for adequately managing future risks
4. Start to identify information, models and tools needed by NBC to manage priority climate risks

Participants

At the workshop, there was a mixture of base personnel and external stakeholders. This workshop summary is being circulated to both workshop participants and to those interested invitees who were unable to attend (see Annex 3). Participants’ roles and expertise were linked to four thematic areas: (1) Operations; (2) Facilities; (3) Training; and (4) Environment. This division formed the structure of workshop break-out groups.

Structure of the day

The day consisted of a mixture of plenary presentations and break-out group discussions.

Session 1 opened with a plenary presentation, with Rafe Sagarin (UA) providing an overview to the project, which was followed by an introduction to climate change from a scientific perspective by Jeremy Weiss (UA) and then the associated consequences for the DoD by Anna Haworth (Acclimatise). This was followed by a short warm-up exercise, whereby participants were asked to work in small groups to record the impacts and consequences for NBC of a recent weather-related event. The purpose of this exercise was to:

- *Identify the consequences of the event, or events in general*
- *Identify the shocks to/ weak points in the system*
- *Understand how NBC responded / responds to weather events.*

At the workshop, small groups highlighted the following examples of events, consequences and responses at NBC:

- winter storm December 2010, leading to:
    - flooding of Tijuana River
    - damage to pier and waterfront facilities
    - loss of training days, in-water training stopped due to health concerns associated with river flooding
    - loss of access to water for the recreational community
    - transportation problems due to closed roads
    - economic loss to the base due to flooding of agricultural fields
    - clean up and repair exercise with associated economic impacts
- wildland fires in October of 2003 and 2007:
    - Navy staff death
    - staff sent home
    - operations stopped
    - destruction of endangered species habitat
    - soil erosion and sedimentation build-up in estuary
    - classed as an emergency and fire prevention gains made
    - NBC provided shelter for local communities
    - Fleet ships transitioned off shore power to relieve electrical grid

This exercise was used as a pragmatic and effective starting point to understand NBC's recent vulnerability and exposure to severe weather events and the associated direct and indirect consequences. Then, by looking at climate change projections and scenarios, we can start to consider whether climate change will make these issues better or worse.

Session 2 focused on defining NBC's key objectives and success criteria. There was a short introductory presentation to the risk management framework (Annex 1, Figure 16) from Bob Khosa (Acclimatise), followed by a break-out group exercise in which functional groups were asked to consider the following questions:

- *What is our group's primary role at NBC?*
- *What are the success criteria – or decision-making criteria? i.e. How do we judge success?*
- *What key issues, policies or decisions are we considering now?*

The purpose of drawing out this information is that it is important to understand the broad objectives and success criteria for the installation, so that when we move on to identify risks, the causal chains linking success or failure to climatic factors can be identified. Each functional group identified their own decision-making criteria, although a number of common themes emerged, including maintaining operational and training readiness, compliance with legislation and regulations and delivering cost-efficient services.

Session 3 focused on future climate scenarios, with two possible futures presented by the UA and then discussed in break-out groups: (1) Warmer and drier with occasional heavy rainfall; and (2) Higher sea level and higher wave surge[viii]. Using the decision-making criteria identified in Session 2, break-out groups generated an inventory of risks associated with each future climate scenario. Where possible, participants were asked to identify key sensitivities and critical thresholds (Annex 1,

[viii] For further reading, Annex 2 provides a list of resources on climate change in the Southwest U.S. and the San Diego region.

Figure 17). At the end of each future scenario, participants were asked to vote, using sticky dots, on the risks they deemed a priority, based on the following criteria:

- *Critical thresholds may be breached*
- *Systems highly sensitive to changes*
- *Decisions with long-term consequences*
- *Where "failure is not an option"*

Over lunch, participants were asked to circulate and review other group's notes from the morning sessions. It was acknowledged that risks are likely to have interconnections between groups and during the working lunch participants were asked to go to other groups' flipcharts and highlight the consequential risks to their own group.

Session 4 was the final session focused on climate risks. A summary list of key cross-cutting issues drawn from Session 2 was presented to the whole group and participants were asked to vote on the priority risks identified across functional groups. The purpose of this exercise was to reach consensus on the issues participants felt were most critical to NBC. These risks are summarized in the key findings section below and fed into the afternoon session on risk management.

Session 5 was conducted with the whole group. We walked through two of the priority risks (see *Key Findings* below) with regard to how they are currently managed and how future experiences with these risks may be managed. To focus the discussion, for each risk we went through a series of questions, as follows:

- *Roles and responsibilities – who manages this risk?*
- *Existing guidance – what current plans are currently in place for this risk?*
- *Existing controls – what is the process for dealing with this risk?*
- *Needs – what informational/human resources/financial resources/monitoring is needed*
- *Barriers – what is getting in the way, or may get in the way of responding?*
- *Opportunities – are there benefits to acting now?*

Key findings

Priority risks

Based on the voting exercise in Session 5, the following issues were deemed highest priority to NBC:

1) **Storm flooding, sedimentation and erosion**:
   - Safety and emergency response
   - Drainage / sewers - contaminants
   - Transportation
   - Infrastructure
   - IT / comms

2) **Sea level rise, erosion and flooding**:
   - Safety and emergency response
   - Critical Infrastructure
   - Waterfront assets
   - IT / comms

3) **Land use and space allocation**

= 4) **Water availability**

= 4) **Fire risk and erosion**
- Personal safety
- Training

6) **Encroachment and conflicts with neighboring communities**

7) **Energy security**

8) **Environmental management and compliance**:
- Species migration
- Coastal habitats

Risk management

The discussion only had time to focus on two issues: a combined Sea level rise/erosion/flooding category; and Water availability. Key points from each of those discussions are given here, with points of particular interest and points that were raised repeatedly throughout the day highlighted in **bold**:

Sea Level Rise/Storm Surge/Erosion/Flooding

- *Roles and responsibilities – who manages this risk?*
    - Design of the infrastructure to withstand a certain about of flooding. There's a threshold in place and level of acceptable risk. From there **the gaps are mitigated by putting emergency resources to use**.
    - Who makes the decisions on the thresholds? (100 year flood or 200 year flood?)
        - Higher level and regional level engineers on the long term horizon
        - Shorter term decisions – a vulnerability assessment is done on what amount of resources will be spent on certain risks
    - They have a fire department on base and a facilities department. There is an **emergency operations center for gathering information and prioritizing** responses.
- *Existing guidance – what current plans are currently in place for this risk?*
    - We don't invest in worst case scenarios, so **we accept risk**.
    - The key is to have reach back to resources that can help you.
    - **We've inherited lots of old infrastructure.**
    - Standardization and incident command management is a reality these days. **Everyone is using the same management and tools to respond**.
    - Each area/installation has its own specific problems and responses. There aren't any codes or polities base wide to deal with that. **There isn't any existing guidance overall.** Each area has to come up with its own solutions.
    - **"I would hate to build a building that is going to flood regularly in 20 years"**
    - Every municipality is facing this same challenge – **how do you plan for the unknowns?** How do you have the flexibility to deal with the barriers to building more adaptive infrastructure and buildings?
- *Existing controls – what is the process for dealing with this risk?*
    - An emergency with just two or three causalities will **quickly prompt interaction with neighboring municipalities**.

- Planning for new infrastructure – you run up against Big Navy. **Current mission and future mission always win out over hypotheticals**. It means we have to be innovative at this level.
- We also have to build to current codes. F&B won't let us build to more frequent 100 year floods and sea level rise. **We can't plan to future impacts**.
- State leadership has really helped move the planning conversation forward and have some consistency.

- *Needs – what informational/human resources/financial resources/monitoring is needed?*
    - Early warning
    - Predictions based on historical data
    - **Standard prediction model for predicting the impacts of the severe events**. Some models show a different picture than the 100 year flood maps.
    - **Real precise elevation data and mapping efforts** for vulnerable bases
    - **Not enough resources,** especially financial
    - We need to do the same thing we've done with energy conservation. They've started to **earmark actual dollars** for more efficient buildings.
    - Need to **reach out to the other agencies** (port authority, Tijuana river, airport, etc) because we can leverage our planning. You can't do this just within your boundary.
    - **A Federal policy across agencies** would alleviate the issue of mixed messages. We would have to follow that.
- *Barriers – what is getting in the way, or may get in the way of responding?*
    - **Our budget for the next 3 to 5 years is all we have** to mitigate against future change. The budget controls everything that will happen.
    - Emergency response personnel communicating with community emergency response and within those groups
    - Communication is always a challenge. Military is very specific on the communications they use for going to war, **civilian communications are separate** (we have gotten better at being able to use the same frequencies).
    - We need **something that communicates the results of this workshop to the "flag" level**. Alignment of the messages as a way to get across the barriers like we saw with energy efficiency.
    - **People are not convinced that climate change is an issue.**
    - The federal government doesn't always listen to the state or local jurisdictions.
- *Opportunities – are there benefits to acting now?*
    - It's encouraging that SERDP wants to know, at the installation levels, what we are discussing and what people need to do this sort of planning. Our goal is to push this sort of information out in a way that will affect policy.
    - Building relationships with other jurisdictions that are facing the same problem.
    - Surveys of San Diego voters show that **people actually want to do something about climate change** despite the political debate and spin.
    - **The DoD sees this as a conversation about security**, right along with energy independence. That gives the issue more credibility. If other jurisdictions could see it that way it would help.

- Maybe we find some common ground regionally because the SW faces similar issues. Like a unified criteria for SLR.

Water Availability

- *Roles and responsibilities – who manages this risk?*
  - We are a customer of the water districts. We went through some litigation. We went through automated water use technologies. We lobbied for water rights. We are at the end of the pipe in Southern California. **We are totally dependent on others** to supply water.
  - But **we lose 20% of our water** through lines on the bases. So we could do more to conserve it.
- *Existing guidance – what current plans are currently in place for this risk?*
  - We have about **a day's worth of storage** if there were a failure at the gate. We don't store enough to sustain the population we host.
  - We go down to mission critical if there is a threat. That extends our ability to sustain support to the fleet.
  - Would a water shortage event trigger this? We **were forced to curtail services** during the September event that was mentioned because of power outages to the sewer lifts.
  - If we cut the population on the base down it goes into the community which likely also faces a water shortage, so **you need to coordinate**.
- *Existing controls – what is the process for dealing with this risk?*
  - Is there a similar capacity for monitoring water as there is for energy? The **public works folks monitor our supply** and are in communication with our suppliers.
- *Needs – what informational/human resources/financial resources/monitoring is needed?*
  - **Better ability to forecast is essential** if you only have a day of storage.
  - The San Diego Foundation funded a collaborative project on downscaling precipitation forecasts and rainwater infiltration for the water authority. **The data the water authority had wasn't answering their questions** because the scale and format was wrong.
- *Barriers – what is getting in the way, or may get in the way of responding?*
  - Do we need to re-examine our agreements with the water providers? Are the allocations enough? **Where are we on the priority list?**
  - **We need funding to fix things**.
  - Reducing your water use affects not only the sewage but also the water quality.
  - The Navy needs to know **where we stand in terms of wanting self-sufficiency**.
- *Opportunities*
  - **We have nuclear aircraft carriers that can generate water.** They aren't rigged to pump the water back onshore. They could also be generators.

Post workshop site visit

UA and Acclimatise express their thanks to Bruce Shaffer and Terrance Smalls for hosting a site visit to NBC's facilities on 8 May. This helped the team to consolidate the information gained workshop

with a wider picture of on-the-ground examples of NBC's exposure to climatic factors and some of the management techniques currently in use.

Next steps

We wish to thank XO CAPT Chris Sund for introducing the workshop and demonstrating the support of NBC leadership.

One of the main goals of this workshop was to establish a working relationship between people from NBC and associated organizations and the UoA project. Through these relationships we can better focus our research and outreach efforts towards helping NBC adapt to a changing climate. We will be following up with specific people to identify data and informational gaps that we can fill. We also welcome direct contact from any individuals or offices that need additional information or are eager to "champion" this approach within NBC. In the short term, we are available to provide follow-up workshops on climate information and adaptation strategies. In the longer term, we will develop tools to help manage climate risk now and to facilitate NBC staff to share climate adaptation strategies elsewhere in DoD. We believe that being part of this pilot project will help establish NBC as a recognized leader in a process of incorporating climate adaptation strategies that is planned to be incorporated throughout the DoD. We also welcome feedback and queries for information on managing climate risk from any part of NBC's operations.

Key contacts

Dr. Raphael Sagarin
Institute of the Environment, University of Arizona
(Ecology, environmental policy, adaptable security strategies)
rafe@email.arizona.edu; 520-626-8010

Dr. Donald Falk
School of Natural Resources and the Environment, University of Arizona
(Fire history, fire ecology, dendroecology, and restoration ecology)
dafalk@email.arizona.edu; 520-626-7201

Dr. Jeremy Weiss
Department of Geosciences, University of Arizona
(Southwest climate variability and change, sea level rise, geographic information systems)
jlweiss@email.arizona.edu; 520-621-6144

Dr. Jaimie Galayda
Project Manager, CLIMAS (Climate Assessment for the Southwest), University of Arizona
jgalayda@email.arizona.edu; 520-622-9062

Sam McNeil
Graduate Research Assistant, Journalism Department, University of Arizona
stmcneil@email.arizona.edu; 206-240-4056

Dr. Anna Haworth
Risk Advisor, Acclimatise
(Climate risk assessment for public and private sectors)
a.haworth@acclimatise.uk.com; +44 (0) 2920 450688

Bob Khosa
Product Development Manager, Acclimatise
(Climate risk assessment for public and private sectors)
b.khosa@acclimatise.uk.com ; +44 (0)1865 554466

Annex 1: Supporting figures

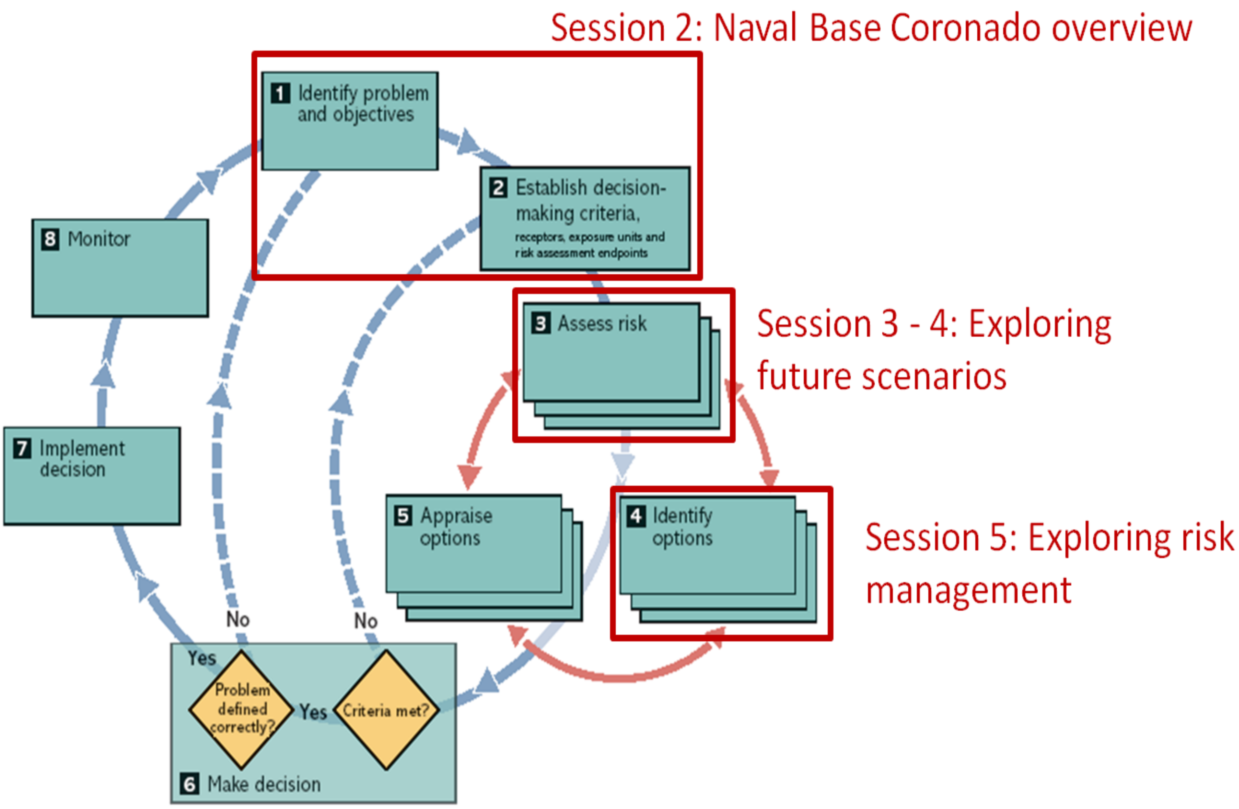


Figure 16: The UKCIP risk-based climate adaptation decision-making framework[ix] and its application at the workshop

This workshop was structured around Steps 1 to 4 of the "Climate change risk-uncertainty-decision making framework" presented in Figure 16. The framework has been widely acknowledged as one which uniquely deals with the uncertainties associated with climate change. It is similar to other processes used for risk management but developed with the primary aim of enabling climate risks to be 'mainstreamed' within any organization's existing risk management processes.

[ix] Willows, R.I. and Connell, R.K. (Eds.). (2003). Climate adaptation: Risk, uncertainty and decision-making. UKCIP Technical Report. UKCIP, Oxford.

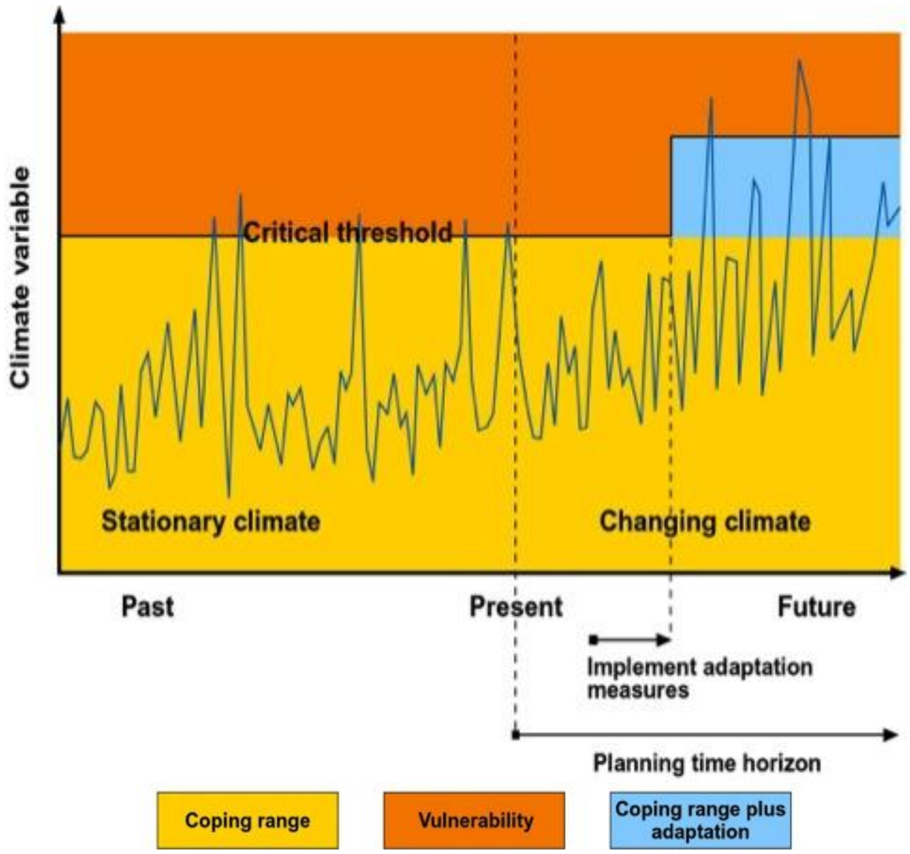


Figure 17: The relationship between coping range, critical threshold, vulnerability, and a climate-related performance criterion[x].

Critical thresholds represent the boundaries between 'tolerable' and 'intolerable' levels of risk. Figure 17 demonstrates what can happen to a critical threshold in the future, when this threshold is based on a stationary (historic) climate. The critical threshold may for example be a maximum safe working temperature for training exercises, or the height of a sea wall. In a stationary climate, the threshold may be designed to tolerate infrequent breaches and its consequences. In a future climate, the threshold may be crossed more often and with greater intensity, now representing an intolerable level of risk. For continued successful operation, this would require adaptation (blue area) in order to raise the acceptable threshold.

[x] Willows, R.I. and Connell, R.K. (Eds.). (2003). Climate adaptation: Risk, uncertainty and decision-making. UKCIP Technical Report. UKCIP, Oxford.

Annex 2: Further reading

Assessment of Climate Change in the Southwest U.S.
www.swcarr.arizona.edu

Climate Action Planning Progress in the San Diego Region

http://www.sdfoundation.org/Newsroom/Publications/StudiesResearchReports.aspx

San Diego's Changing Climate: A Regional Wake-Up Call

http://www.sdfoundation.org/Newsroom/Publications/StudiesResearchReports.aspx

Sea Level Rise Adaptation Strategy for San Diego Bay

http://www.icleiusa.org/static/San_Diego_Bay_SLR_Adaptation_Strategy_Complete.pdf

Annex 3: Participants and invitees

Recommended Groups for University of Arizona DoD Assess Risk and Readiness for Climate Change Impacts and Adaptation As of 05/06/2013					
CHAMPION	ATTENDED	NAME	TITLE/ORGANIZATION	PHONE #	E-MAIL ADDRESS
Facilities					
		Richard Johnston	DPWO, NBC	(619) 545-1111	Richard.Johnston@navy.mil
	X	McCay, Patrick	Planning Lead, NBC	(619) 767-7261	Patrick.mccay@navy.mil
	X	Joni Mitchell	GIS	(619) 545-1114	joni.mitchell@navy.mil
	X	Deb McKay	Planner	(619) 553-8741	Deborah.mckay@navy.mil
		Matthew Wright	Planner	(619) 437-9037	Matthew.G.Wright@navsoc.socom.mil
		Brenda Bautista	Planner	(619) 545-1123	brenda.bautista@navy.mil
		Dana Spaccarotella	Planner	(619) 545-1124	Dana.n.spaccarotella@navy.mil
	X	Scott A. Goodman, CPP, PSP	Physical Security Specialist	(619) 767-1792	scott.a.goodman1@navy.mil
		Jennifer Thomas	Planner	(6190 545-6721	Jennifer.l.thomas4@navy.mil
	X	Terrance Smalls	Planner	(619) 767-7259	Terrance.smalls@navy.mil
	X	James Hirsch	Senior Redevelopment Planner	(619) 686-7269	jhirsch@protofsandiego.org
	X	Angela Jamison	Airport Planning Manager	(619) 400-2464	ajamison@san.org
	X	Brandon Workman	MWR Manager	619-522-8680	Brandon.workman@navy.mil
	X	Khristine Avendano	Utilities Manager	(619) 545-1868	khristine.avendano@navy.mil
	X	Brian Javier	Planner	(619) 572-9117	Brian.javier@navy.mil
	X	Laura Salle	Engineer	(619) 572-9117	Laura.salle@navy.mil

	X	Vilay "Joyce" Ferrenburg	Engineer	(619) 556-7946	Vilay.ferrenburg@navy.mil
Operations					
		LTJG Kevin Scales	OIC/ATC Facility Officer NOLF Imperial	(619) 437-9417	Kevin.scales@navy.mil
		LT Lee Fox	NAB OIC	(619) 437-2075	lee.fox@navy.mil
	X	James Murray	Emergency Manager	(619) 767-1769	James.murray3@navy.mil
	X	Bill Delano	Air Operations	619-545-8261	William.delano@navy.mil
	X	Salvador Cuellar	Deputy Chief of Police	(619) 767-1597	Salvador.cuellar@navy.mil
	X	Michael Knox	Operations Officer	(619) 313-2307	mknox@score.com
	X	Cervantes, Chris	Director of Ops	619-437-3633	christopher.t.cervan@navy.mil
	X	LCDR Sarah Sherrod	Air Operations	619-545-2632	Sarah.sherrod@navy.mil
		Perez, Lou	Environmental Lead, NBC	(619) 545-3429	luis.perez3@navy.mil
	X	Bruce Shaffer	CPLO	(619-545-4134	Carl.shaffer@navy.mil
	X	LCDR Eric Gatley	SCI Assist ICO	(619) 572-5721	eric.gately@navy.mil
Training					
		Navarro, Perry	SSTC South Scheduler, NSWC	(619) 437-3202	Perry.Navarro@navsoc.socom.mil
	X	Chris Cervantes	COMNAVBEACHGRU 1 Scheduler	(619) 437-3634	Christopher.t.cervan@navy.mil
		Donald C. Johnson	SSTC North Scheduler, NSWC	(619) 437-2476	Donald.c.johnson1@navy.mil
	X	Cisneros, Rafael GMC	SERE West, RTSWS LCPO	(619) 545-4526	Rafeal.Cisneros@navy.mil
	X	Scott Penwell	Environmental Manager	(619)537-3114	Scott.Penwell@navsoc.socom.mil
		Dennis Gilbert	Facility Manager	(619) 478-1373	Dennis.Gilbert@navsoc.socom.mil
	X	David Busby	Training and Readiness	(619) 545-5120	David.busby@navy.mil
	X	Peter Kennedy	Regional Environmental Coordinator	(619) 532-2350	Peter.a.kennedy@navy.mil
		Adrianne Saboya	Environmental Program Manager	(619) 537-1857	Adrianne.saboya@navsoc.socom.mil
	X	Suzanne Smith	Coastal Commission Liason	(619) 532-2284	Suzanne.M.Smith@navy.mil

X		Tim Latas	Range Sustainment Coordinator	(619) -545-5347	Timothy.latas.ctr@navy.mil
Environmental					
	X	Melissa Booker	Natural Resources Biologist	(619) 545-7188	Melissa.Booker@navy.mil
		Ryan Anson	Environmental Engineer	(619) 545-5549	Ryan.anson@navy.mil
	X	Arlene Arnold	Natural Resources	(619) 545-5551	Arlene.arnold@navy.mil
		Bryan Munson	Botanist	(619) 545-7186	Bryan.munson@navy.mil
	X	Tiffany Shepherd	Natural Resources	(619) 5453703	Tiffany.shepherd@navy.mil
		Jacqueline Rice	Environmental Lead	(619) 545-9339	jacqueline.rice@navy.mil
		John Crow	Regional Environmental Coordinator	619-532-2749	John.crow@navy.mil
		Michelle White	Senior Environmental Specialist	(619) 686-7297	mwhite@portofsanddiego.org
	X	Dani Boudreau	Outreach Manager	(619) 575-3613	dboudreau@trnerr.org
	X	Paul Manasjan, M.S. R. E.H. S.	Director Environmental Affairs	(619) 400-2783	pmanasja@san.org
	X	Noelle Shaver	Archaeologist	619-532-2090	Noelle.shaver@navy.mil
	X	Vicky Ngo	NEPA Planner	(619) 545-2168	Anh.ngo@navy.mil
	X	Nicola Hedge, MPIA, LEED Green Associate	Manager, Climate Initiative	(619) 814-1384	nicola@sdfoundation.org
	X	Cody Hooven	Environmental Specialist, San Diego Port Authority	(619) 686-8162	chooven@portofsandiego.org
	X	Kari Coler	Natural Resource Specialist	(619) 556-9904	kari.coler@navy.mil
	X	Bryan Munson	Botanist	(619) 545-7186	Bryan.munson@navy.mil
University of Arizona					
	X	Dr. Raphael Sagarin	Associate Research Scientist, Institute of the Environment	520-626-8010	rafe@email.arizona.edu
		Dr. Jonathan Overpeck	Co-Director, Institute of the Environment	520-626-4364	jto@email.arizona.edu
		Dr. Gregg Garfin	Deputy Director for Science Translation & Outreach, Institute of the Environment	520-626-4372	gmgarfin@email.arizona.edu

	X	Dr. Don Falk	Research Associate Professor, School of Natural Resources and the Environment	520-626-7201	dafalk@email.arizona.edu
		Dr. Peter Troch	Science Director, Biosphere 2	520-626-1277	patroch@hwr.arizona.edu
	X	Dr. Jeremy Weiss	Research Scientist, Department of Geosciences	520-621-6144	jlweiss@email.arizona.edu
	X	Dr. Anna Haworth	Risk Advisor, Acclimatise	+44 (0) 7968 109252	a.haworth@acclimatise.uk.com
		Alastair Baglee	Director, Acclimatise Interactive	+44 (0) 2920 450688	a.baglee@acclimatise.uk.com
	X	Sam McNeil	Graduate Research Assistant	206-240-4056	stmcneil@email.arizona.edu
	X	Dr. Jaimie Galayda	Project Manager, CLIMAS	520-622-9062	jgalayda@email.arizona.edu
	X	Dr. Bob Khosa	Product Development Manager, Acclimatise	+44 (0)1865 554466	b.khosa@acclimatise.uk.com

Appendix 3: Navy Installation Emergency Management Program Manual (CNI 3440.17)

Standard 4: Assessments

Background. Emergency Management planning must be predicated on critical asset, threat/hazard, vulnerability, consequence, and response capability assessments. These assessments are used to evaluate an installation's ability to respond to a threat/hazard, protect the population on the installation and implement future strategies to mitigate risks.

References.

(a) OPNAV Instruction 3440.17(Series) Navy Installation Emergency Management (EM) Program (22 July 2005)
(b) National Fire Protection Association (NFPA) Standard 1600 "National Preparedness Standard on Disaster/Emergency Management and Business Continuity Programs" (5 February 2004)
(c) DoD Instruction 2000.16(Series) Antiterrorism (AT) Standards (14 Jun 2001)
(d) NTTP 3-11.24 Multiservice Tactics, Techniques, and Procedures for NBC Aspects of Consequence Management (July 2001)
(e) DoD Handbook 0-2000.12-H(Series) Protection of DoD Personnel and Assets from Acts of Terrorism (9 February 2004)
(f) OPNAV Instruction 3300.55(Series) Navy Combating Terrorism Program Standards (9 April 2001)
(g) DoD Instruction 2000.18(Series) Department of Defense Installation Chemical, Biological, Radiological, Nuclear and High-Yield Explosive (CBRNE) Emergency Response Guidelines (4 Dec 2002)
(h) OPNAV Instruction 5530.14(Series) Navy Physical Security (1 May 2001)

Scope. The Navy Installation EM Program shall establish assessment criteria for all Regions and Installations worldwide per reference (a).

Responsibilities. Per references (a) and (b), Regional and Installation Commanders are responsible for ensuring that critical infrastructure, threat/hazard, vulnerability, consequence and response capability assessments are completed prior to the preparation of the Regional and Installation EM Plans. Regional and Installation Commanders shall utilize existing threat & vulnerability assessments conducted through the AT Program, whenever possible. Table 4-1 provides guidance on what organizations should be involved in preparing the various assessments. Fire, HAZMAT, CBRN-Defense, EOD, EMS, civil and electrical engineering subject matter experts should assist these organizations in the preparation of the assessments. All hazard and consequence assessments should be integrated with those of adjacent/nearby Federal/State/Local/Regional/ Installation/Host Nation agencies and departments to the greatest extent possible.

EM capabilities shall be organized, utilized, and assessed on a Regional and Installation basis. EM Capability Assessments (see below) are executed at no more than an annual interval to allow Regional and Installation Commanders to validate their ability to achieve the appropriate EM capability as determined by the group designation, categories of personnel within their jurisdiction, and the resources available for employment during an emergency.

Strategy. Risk is a function of threats/hazards, vulnerability to threats/hazards, and resulting consequences if these threats/hazards were to strike a critical infrastructure on an installation. Risk Management is a continuous process of assessing critical infrastructure and evolving hazards, threats, vulnerabilities, consequences, and existing response capabilities to determine what additional actions

are needed to achieve/maintain a desired level of readiness. This also is sometimes referred to as a Risk Analysis or Evaluation although as shown in Figure 4-1, risk evaluation is really only one part of an overall Risk Management process.

These assessments should incorporate information and recommendations from a variety of sources including, but not limited to, Joint Service Integrated Vulnerability Assessments (JSIVA), Chief of Naval Operations Integrated Vulnerability Assessments (CNO IVA), CIP planning and assessments, and Continuity of Operations (COOP) planning, and exercise deficiencies.

In general, information on local natural/technical hazards is readily available from State and Local (and some Host Nation) agencies and departments. Regional and Installation EM Programs should coordinate threat and hazard assessments with State and Local emergency management agencies. States are required to submit annual capability assessments to the Department of Homeland Security (DHS) for out-year funding considerations. It is beneficial for Regions and Installations to team with the State and Local agencies on these assessments.

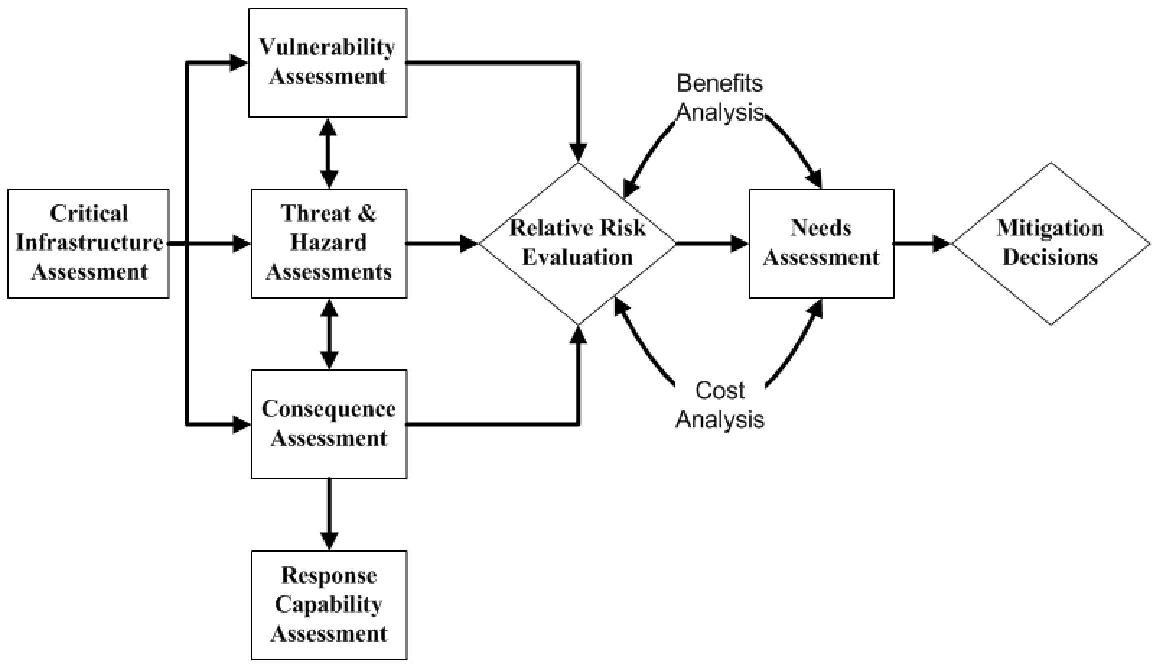
Table 4-1 Types of Assessments

Responsible Organizations	Assessments
AT	**Critical Infrastructure Assessment:** identification of Regional and Installation critical assets/infrastructure and personnel necessary to carry on Mission Essential Functions (MEFs).
NCIS	**Threat Assessment**: determination of specific terrorist or criminal threats to a Region, Installation, or geographic area.
EM	**Hazard Assessment**: identification of hazards specific to a Region, Installation, or geographic area.
AT	**Vulnerability Assessment**: determination of the extent of vulnerability of critical assets and personnel onboard an Installation to threats and hazards.
EM	**Consequence Assessment**: determination of consequences of attacks and hazards that strike an installation at its current level of preparedness.
EM	**Response Capability Assessment**: determination of existing manpower and equipment capabilities and established procedures to mitigate consequences of identified hazards/threats.

Risk factors resulting from assessments for the various threats and hazards to each critical asset/ infrastructure must be compared against each other to determine relative risks. This Relative Risk Evaluation will culminate in the Needs Assessment (also known as a Risk Mitigation Assessment) that will assist in future resource allocation, prioritization, and acquisition planning. Costs/Benefits need to be a considered when deciding to acquire new resources.

The overall Risk Management process is shown in Figure 4-1. This process drives continuous improvement in a comprehensive Regional and Installation EM Programs.

Figure 4-1: Overall Risk Management Process



Risk Management Steps:

1. Risk Determination: The following risk equation will be used to produce a risk determination that takes into account existing response capabilities and safeguards:

$$Risk = \frac{Critical\ Infrastructure\ (CI) \times [Threat\ (T)\ or\ Hazard\ (H)] \times Vulnerability\ (V) \times Consequence\ (C)}{Response\ Capability\ (RC)}$$

where

- *The Critical Infrastructure factor is a measure of the relative value of the installation and asset with respect to strategic, critical, and mission-essential functions*
- *Threat and Hazard factors allow measurement of the probability that a specific type of attack or natural/man-made hazard will strike an asset*
- *Vulnerability is a measure of the probability that in-place installation and asset safeguards against a threat or hazard will fail*
- *Consequence is the magnitude of the negative effects if the attack is successful or hazard occurs*
- *Response Capability is a measure of the response level based on the types of existing response teams, procedures, equipment, training, and exercising. A robust response can mitigate the consequences of a threat or hazard after it has occurred. This is different than pre-threat/hazard safeguards (e.g. AT Standards and earthquake/severe weather construction standards) that may prevent an attack or mitigate consequences by being in place before the threat/hazard strikes.*

2. Identify Threats and Hazards. Table 4-2 lists typical threats and hazards per reference (b) that need to be evaluated for applicability to installation critical assets as the first step in the Risk Management

process. Natural hazards are those hazards that may have potential direct or indirect impact on the Region/Installation and may occur without the influence of people or organizations.

Table 4-2 Typical Hazards and Threats

Natural and Technological Hazards (List is not all inclusive)
• Destructive Weather (Tropical Cyclone, Hurricane, Typhoon, Tornado, Storms, Drought)
• Seismic/Geological (Earthquake, Tsunami, Volcano, Landslide, Mudslide)
• Flood, Seiche, Tidal Surge
• Fire (Forest, Wilderness, Urban/Structural)
• Winter Storms (Snow, Ice, Hail, Sleet, Avalanche)
• Extreme Temperatures (Heat, Cold)
• Lighting Strikes
• Hazardous Material (HAZMAT)/Toxic Industrial Material (TIM) spill/release
• Transportation Accidents (Aircraft, Ship, Barge, Rail, Vehicle, Bus)
• Building/Structural Collapse
• Power/Energy/Utility Failure
• Fuel/Resource Shortage
• Air/Water/Soil Pollution or Contamination (coordinated with Environmental Plans)
• Dam/Levee Failure
• Financial System/Banking Collapse
• Communications/Information Technology Interruptions/Loss
Criminal and Terrorist Threats (List is not all inclusive)
• Intentional Release - Chemical
• Intentional Release – Contagious/Infectious Biological
• Intentional Release – Non-Contagious/Non-Infectious Biological
• Intentional Release/Event - Radiological
• Intentional Event - Nuclear
• Intentional Event - Explosive or Incendiary
• Intentional Event – Electromagnetic and/or Cyber
• Sabotage
• Civil Disturbance, Riot, or Mass Panic/Hysteria
• Arson

3. Critical Infrastructure Assessments. Critical infrastructure consist of those systems/assets essential to plan, mobilize, deploy, and sustain Mission Essential Functions (MEFs) and supporting essential assets/services whose loss or degradation jeopardizes the ability of the Navy to execute the National Military Strategy. Critical Infrastructure Assessments identify strategic, operational, and mission-essential assets in need of special protection. A non-mission-essential asset does not require special protection. An asset can be tangible (vessels, facilities) or intangible (like information). Table 4-3 provides installation levels/values and infrastructure/asset values/examples as the second step in the Risk Management process. Table 4-3 is based, in part, on reference (c) methodology, the Resource and Asset Priority listing in reference (d) and installation grouping criteria in reference (a). Note that the

individual rows in the two columns are not aligned. For instance, a Strategic installation (value = 4) can have assets with various values (4, 2, 1, 0).

Reference (c) discusses two DoD processes/matrices that are sometimes used by Regions and installations to determine critical assets: MEVA - Mission Essential Vulnerable Area methodology and CARVER - Criticality, Accessibility, Recuperability, Vulnerability, Effect, and Recognizablity. MEVAs consist of information, equipment, property, and facilities recommended annually by the Installation Commander as requiring additional protection through application of increased physical security measures, procedures, and equipment.

CARVER is a targeting methodology. A more flexible, software tool, called CARVER^2 has been developed by the National Infrastructure Institute (www.ni2cie.org) to assist state and local homeland security officials to better identify and protect potential terrorist targets. CARVER^2 provides a method of comparing and ranking critical infrastructure and key assets across all sectors (i.e. water systems versus transportation versus energy). Relative worth is determined by analyzing criticality (the number of people affected, cost to rebuild/replace, potential deaths), accessibility by terrorists, recoverability (time needed to replace asset), vulnerability (blast attack, chemical/biological attack), redundancy, and interdependence (are other critical infrastructures affected by loss of asset?). It is important for EMOs to recognize that unlike Table 4-3, MEVA, CARVER and CARVER$^{2™}$ methodologies generally do not rank critical assets by strategic/critical/ mission essential military capabilities. A discussion of other limitations of the CARVER^2 methodology for military assessments is contained below.

Table 4-3 Critical Infrastructure Assessment Criteria

CRITICAL INFRA-STRUCTURE (CI) FACTOR	INSTALLATION LEVELS /VALUES	ASSET VALUES & ASSET EXAMPLES
CI Factor = Installation Value + applicable Asset Value	STRATEGIC (Strategic Asset/High Threat Installations) **(4)**	**(4)** • Nuclear & Chemical Weapons and Alert/Mated Delivery Systems • Nuclear reactors and Category I & II Special Nuclear Materials • Strategic Command, Control and Communications Assets (e.g. Dispatch Centers, EOCs, ROCs) • Strategic intelligence gathering facilities and systems • Presidential transport systems
	OPERATIONAL (Operational Bases and Critical C4ISR) **(2)**	**(2)** • Operational Base (can deploy assets) Command, Control and Communications Assets (e.g. Dispatch Centers, EOCs, ROCs) • Infrastructure associated with operational assets (e.g. fuel, power, cooling water distribution nodes/equipment/systems) • Critical alert systems, forces, and facilities • Critical intelligence gathering facilities and systems • Emergency Response equipment/storage buildings. • Category I arms, ammunition, and explosives • Critical research, development and test assets.

		SUSTAINMENT & SUPPORT ACTIVITIES **(1)**		**(1)** • Operations Centers • Dispatch Centers • Hospitals • Arms, ammunition, and explosives • Precision guided munitions • Category II arms, ammunition and explosives • Fuel/power/water/supply storage facilities • Mission-essential research, development, and test assets.
		NON-MISSION ESSENTIAL (Administrative and Training Activities) **(0)**		**(0)** • Exchanges and commissaries, fund activities • Controlled drugs and precious metals • Training assets • Non-mission essential research, development, and test assets

4. Threat Assessments. Terrorism and sabotage threats to strategic, operational, and mission essential assets must be assessed. Regional and Installation Commanders should continuously ensure that forces are trained to maximize the use of threat assessments and intelligence derived from liaisons to civil and military law enforcement and public safety agencies and departments as well as EM, meteorological, environmental, public health, and medical syndromic surveillance processes and procedures.

Regional and Installation Commanders shall utilize existing threat assessment methods as required by references (c) and (e) to gather and analyze the threats potentially impacting their installation on no less than an annual basis. Threat information should be integrated to meet the collective needs of EM, CBRNE Preparedness, Combating Terrorism (CbT), AT, CIP, and COOP planning. See references (f) and (g) for CBRNE-specific guidance.

In accordance with references (c) and (e), a threat assessment reviews the factors of a terrorist group's existence/operational capability, intentions (targeting), activity (history and type), and the operational environment within which friendly forces operate. Table 4-4, based on reference (c), provides threat assessment criteria as the third step in the Risk Management process. The Defense Intelligence Agency at Anacostia Annex (Bolling AFB) sets the overall threat level (column 2) for DoD installations based on the criteria noted in columns 3, 4, 5, and 6. DoD installations. Even though reference (c) could be interpreted to mean that certain types of CBRNE threats are only credible at elevated threat levels, the following conservative approach shall be utilized: CBR-E threats shall be deemed credible at all four threat levels and (N)uclear and <u>infectious</u> biological threats shall be deemed credible at the Significant and High threat levels.

Table 4-4: Terrorist Threat Assessment Criteria

Threat (T) (probability) Factor	Threat Level	Operational Capability NOTE 1	Intentions	Activity	Operating Environment
(10)	**High**	Mass Casualty (CBRNE) producing attacks are preferred method.	• Anti-US. • Recent substantial attack.	• Operationally active. **NOTE 2** • Key operative movement.	• Favors the terrorist. • Substantial DoD presence.
(2)	**Significant**	Personnel Attacks and/or Mass Casualty (CBRNE) producing attacks are preferred methods but limited operational capability is present for mass casualty attack.	• Anti-US. • Attacks have occurred elsewhere	• Intelligence collection. • Contingency Planning. • Weapons Caches.	Neutral
(1)	**Moderate**	Terrorist groups are present.	• Anti-Host Nation (not Anti-U.S. activity).	• Target ID. • Suspect Activities. • Disruption.	Favors Host Nation/US
(0.1)	**Low**	No terrorist groups detected	Are non-threatening	• Fund Raising. • Safe Havens Present.	Favors Host Nation/US

Note 1: The Operational Capability determines the baseline threat level from which all other criteria are influenced.

Note 2: A Terrorist Warning Report will be issued when terrorist groups are operationally active and specifically targeting U.S. interests (corresponding to a High Threat Level).

5. Hazard Assessments. Per reference (b), Regional and Installation emergency management should consider all hazards that may confront the installations, to include natural hazards and hazards other than CBRNE. These hazards will vary from each installation. For example, hurricanes may be a significant natural hazard concern in the Southeast Region, but not in the Pacific Northwest. Tsunamis are of concern in the Pacific Northwest, but not in the Southeast. Toxic Industrial Materials (TIMs) are of concern at almost all installations. TIMs include Toxic Industrial Chemical (TIC), Toxic Industrial Biological (TIB), and Toxic Industrial Radiological (TIR) materials.

The methods and methodologies for assessing hazards other than CBRNE are readily available from DHS (FEMA), the Environmental Protection Agency, and the Department of Transportation. NOAA issues annual hurricane season probability and severity predictions. The National Climatic Data Center (http://www4.ncdc.noaa.gov) maintains a database of storm events for the United States. Search of the database can be by county, date, and type of event. Most State, Local, and Host Nation emergency management agencies and departments have comprehensive hazard assessments already available and can be a valuable source of information. Table 4-5 provides hazard assessment criteria as the fourth

step in the Risk Management process. FEMA recommends including several factors into the hazard assessment: the time available until the onset of the hazard and the possibility of a single event to cascade and cause other failures. Each Installation EMO must rank all hazards by relative probability to each other before assigning Table 4-5 probability and onset values to each hazard. The individual rows in the two columns in Table 4-5 are independent of each other. For instance, each hazard may have its own unique set of values for probability and onset.

Table 4-5: Natural and Technological Hazard Assessment Criteria

Hazard Category (H Factor)	Hazard Relative Probability (Values) & Criteria	Onset Values
H Factor = Hazard Relative Probability value + applicable Onset value	**(10) High** Hazard is at least an order of magnitude more likely to occur than other identified hazards.	Minimal or no warning **(2)**
	(2) Significant Hazard is at least twice as likely to occur as other identified hazards.	6 to 12 hours warning **(1)**
	(1) Moderate Default hazard level for an identified hazard (use this level unless criteria is more fitting).	12 to 24 hours warning **(0.5)**
	(0.5) Low Hazard is at least half as likely to occur as other identified hazards.	24 to 48 hours warning **(0.1)**
	(0.1) Very Low Hazard is at least an order of magnitude less likely to occur than other identified hazards.	More than 48 hours warning **(0)**

6. Vulnerability Assessments. Vulnerability is a measure of the probability that in-place installation and asset safeguards against a threat or hazard will fail. It may not be possible to mitigate the effects of some natural hazards such as hurricanes, earthquakes, tornadoes, and other destructive weather systems. Other natural hazards and off-base technological hazards may be mitigated by the proximity of the critical asset to the hazard (e.g. - tsunami, flood/mudslide, volcano, wildfires, commercial chemical plant).

Installation Commanders must conduct a local AT vulnerability assessment per references (c) and (e) for facilities, installations, and critical nodes within their area of responsibility on an annual basis or more frequently as required. This vulnerability assessment addresses the broad range of threats to the installation and its personnel and should be broadened to include all natural and man-made hazards. In

accordance with reference (f), Installation Commanders shall prioritize, track, and report to the Regional EM actions planned to be taken to address vulnerabilities identified in the annual installation vulnerability assessments.

Vulnerability assessments of installations should:

- Focus on the command's overarching EM and AT programs. The Navy Vulnerability Assessment Management Program (VAMP) [also called NOVA - Navy Operational Vulnerability Assessments] database is a source of vulnerabilities and mitigation actions contained in AT assessment reports that correspond to applicable DoD AT Standards in reference (f). This database is managed by OPNAV N34 to document findings by the CNO IVA/Joint Staff (JSIVA) AT assessment teams conducted by OPNAV N34 and DTRA. CNO/IVA and JSIVA assessments are conducted on a tri-annual basis. VAMP is also a tool that the Regional and Installation Commander may use to document follow-on, annual AT self-assessments and AT/FP and EM exercise findings.
- Determine asset-specific vulnerabilities applicable to particular threats and hazards.
- Assess the scope of an asset's vulnerability i.e., single weakness or multiple weaknesses in the safeguard system.
- Assess the degree of difficulty in exploiting the vulnerability
- Analyze installation structure and activities from an adversary's perspective to obtain a basis for understanding true, rather than hypothetical, vulnerabilities. This may be accomplished through written questionnaires and surveys.
- Be classified in accordance with the appropriate Security Classification Guides.
- Be disseminated for internal use at least annually.

The fifth step in the Risk Management process is to estimate the degree of vulnerability relative to each asset and threat/hazard using Table 4-6. Table 4-6 is based, in part, on standards in references (c) and (f) and this manual. If a particular asset has a unique combination of fences/barriers or RAM that is not listed in Table 4-6, then an asset-specific vulnerability value may need to be determined. Selection of the most appropriate vulnerability value (from the four levels) in columns 2 or 3 should be based on an average value derived from the sub-criteria listed under each of the four levels in columns 2 and 3 in Table 4-6.

For instance, a critical asset may be protected from natural and technological hazards by significant compliance with building codes (value = 0.25); HVAC controls which are accessible to untrained building occupants, minimal sheltering-in-place plans exist, and it has a partially effective mass notification system (value = 0.50); but only 25% of the personnel have received EM Awareness training (value = 0.75). For this situation a value of 0.5 may be most appropriate. Lastly, the individual rows in columns 2 and 3 are independent of the recognizability values in column 4.

Table 4-6: Vulnerability Assessment Criteria

<table>
<tr><th rowspan="2">Vulnerability Category
(V Factor)</th><th colspan="2">Critical Asset Vulnerability Values
(Expected failure probability of in-place safeguards to prevent damage to critical assets and populations from credible threats/hazards)</th><th rowspan="2">Recognizablity Value
(Use a value of 5 for all credible natural/ technological hazards and a nuclear or infectious biological attack)</th></tr>
<tr><th>Terrorist and Criminal Threats
• <u>Physical Security and Terrorist Incident Measures in ref (b)</u> (e.g. installation and/or asset security fences & lighting, access barriers, Random Anti-terrorist Measures, intrusion alarms, explosives detection, stand-off, blast mitigation/ballistic glass, protected HVAC intakes, security patrols)
• <u>Sheltering-in-Place, Evacuation Plans, Mass Notification System</u>
• <u>AT and EM Awareness Training (Cat 1-5)</u></th><th>Natural and Technological Hazards
Compliance with current:
• <u>UFC building construction codes (e.g. building standoff, earthquake anchoring, new and retrofitted building codes)</u>
• <u>HAZMAT Storage/Handing codes</u>
• <u>Sheltering-in-Place, Evacuation Plans, Mass Notification System</u>
• <u>EM Awareness Training (Cat 1-5)</u></th></tr>
<tr><td rowspan="3">V Factor = <u>Applicable</u> Critical Asset Vulnerability Value x Recognizablity Value</td><td>(0.90)
• No asset or installation fences (includes waterborne barriers)
• No standoffs, Random Anti-terrorism Measures (RAM), or intrusion alarms implemented.
• No HVAC controls
• No sheltering-in-place or evacuation plans
• No Mass notification system
• No AT/EM Awareness training Program or training
• No IT firewalls and protocols to protect against cyber attacks.</td><td>(0.90)
• Very Low Compliance with current codes
• No HVAC controls
• No sheltering-in-place or evacuation plans
• No Mass notification system
• No EM Awareness training Program or training</td><td>(5)
Asset is clearly recognizable under all conditions and from a distance. Requires little or no training for recognition.</td></tr>
<tr><td>(0.75)
• One guarded, installation fence/waterborne barrier with no asset fence/wall.
• Stand-offs implemented but no RAM or intrusion alarms
• HVAC controls not accessible to building occupants
• No sheltering-in-place plans
• No Mass notification system
• AT/EM Training Program but only 25% of installation trained
• No IT firewalls and minimal protocols to protect against cyber attacks.</td><td>(0.75)
• Low Compliance with current codes
• HVAC controls not accessible to building occupants
• No sheltering-in-place plans
• No Mass notification system
• EM Awareness Training Program but only 25% of installation trained</td><td>(4)
Asset is easily recognizable at close range and requires a small amount of training for recognition.</td></tr>
<tr><td>(0.50)
(Nuclear & infectious bio terrorist default value if threat level is High)
• One guarded, installation fence/waterborne barrier with one asset fence/wall.
• Stand-offs and RAM implemented but no intrusion alarms, explosive detection capability
• HVAC controls accessible to untrained building occupants
• Partially effective mass notification system
• AT/EM Awareness Training Program but only 50% of installation trained
• Basic IT firewalls and protocols to protect against cyber attacks.</td><td>(0.50)
• Moderate Compliance with current codes
• HVAC controls accessible to untrained building occupants
• Minimal sheltering-in-place plan
• Partially effective mass notification system
• EM Awareness Training Program but only 50% of installation trained</td><td>(3)
Asset is difficult to recognize at night or in bad weather, or might be confused with other nearby assets. Requires some training for recognition</td></tr>
</table>

	(0.25) (Nuclear & infectious bio terrorist default value if threat level is Significant) • Two guarded, installation fences/waterborne barriers (outer, inner) and asset fence/wall OR one outer guarded, installation fence and two asset fences/walls • Stand-offs, RAM, intrusion alarms, surveillance cameras, and partial CBRNE detection capability implemented • Building occupants are trained to operate HVAC controls • Mostly effective mass notification system • AT/EM Awareness Training Program. 75% of installation trained • Basic IT firewalls and robust protocols to protect against cyber attacks.	**(0.25)** • Significant Compliance with current codes • Building occupants are trained to operate HVAC controls • Adequate sheltering-in-place plan • Mostly effective mass notification system • EM Awareness Training Program. 75% of installation trained	**(2)** Asset is difficult to recognize at night or in bad weather, even at close range; it is easily confused with other nearby assets. Requires extensive training for recognition.
	(0.10) • Two guarded, installation fences/waterborne barriers (outer, inner) and asset fence/wall OR one outer installation fence and two asset fences/walls. Additional vessel quarterdeck or building guard(s). • Standoffs, RAM, intrusion alarms, surveillance cameras, and significant CBRNE detection capability implemented • HVAC controls can be remotely activated • Redundant and effective mass notification system • AT/EM Awareness Training Program. 90% of installation trained • Robust IT firewalls and protocols to protect against cyber attacks.	**(0.10)** • High Compliance with current codes • HVAC controls can be remotely activated • Effective sheltering-in-place plan • Redundant and effective mass notification system • EM Awareness Training Program. 90% of installation trained	**(1)** Asset cannot be recognized under any conditions, except by experts.

Further guidance on CBRN vulnerability assessments may be found in references (d) and (h).

7. Consequence Assessments. The purpose of the Consequence Assessment is to determine the probable consequences of a threat or hazard occurring at an Installation's current level of preparedness/response capability. Table 4-7 provides consequence assessment criteria as the sixth step in the Risk Management process. The values in Table 4-7 also take into account follow-on events, what FEMA calls "cascade" effects. The consequence category (C Factor) for a particular asset and threat/hazard is determined by adding together the three appropriate consequence values for each threat/hazard to a particular asset. Care should be taken when using Table 4-7 to assign values that reflect true impacts. Note that the individual rows in columns 2, 3, and 4 are independent of each other. For instance, a hazard or threat may cause 11 to 100 deaths (value = 2); 1 to 10 million dollars of damage (value = 1); and create a short term vulnerability in national defense (value = 3).

- Installation Death and Injury consequence values for:
  - Earthquakes, an airborne release resulting from a chemical and radiological attack, and/or nearby off-base chemical plant, volcano, and food/water bioterrorism attack need to reflect the <u>installation-wide</u> impacts.
  - High explosives and on-base TIM events need to be based on the population of the <u>asset</u>.
  - Certain natural hazards (e.g. tsunami wave inundation, tornado, flood, wildfire, land/mud slide, severe weather) are asset-specific but can affect other parts of the installation beyond the critical asset.

- Infrastructure/Asset Costs and Mission Capability consequence values for all threats/hazards need to be based on the asset costs associated with replacement, decontamination, and cleanup.

The above approach avoids inappropriately discounting the impacts of those types of threats and hazards that if analyzed on just an asset-specific basis, may lead to an unrealistically low Consequence Factor.

Table 4-7: Consequence Assessment Criteria

Consequence (C) Factor	Consequence Values		
	Installation Death or Injury (Cat 1-5 personnel)	***Installation/Asset Infrastructure*** *(includes environmental remediation by EPA)*	Asset Mission Capability
C Factor = sum of all three applicable consequence values	**> 1,000 deaths or serious injuries (4)**	**> $1 billion (4)**	**Creates strategic and/or operational, <u>long-term</u> vulnerabilities in national defense. (4)** *(Conventional or nuclear destruction of strategic and/or critical asset capabilities that cannot be duplicated by other assets)*
	101 to 1,000 deaths or serious injuries (3)	**> $100 million to $1 billion (3)**	**Creates operational, <u>short-term</u> vulnerabilities in national defense. (3)** *(Destruction of critical asset capabilities that can be, with time, duplicated by other assets)*
	11 to 100 deaths or serious injuries (2)	**> $10 million to 100 million (2)**	**Creates <u>long-term</u> disruptions in mission essential capabilities. (2)** *(Extended blockage of a strategic port or airfield)*
	1 to 10 deaths or serious injuries (1)	**1 million to $10 million (1)**	**Creates <u>short-term</u> disruptions in mission essential capabilities. (1)** *(Temporary outage with available compensatory capability, prolonged severe weather)*

		No deaths or serious injuries; only relatively minor injuries **(0)**		**< $1 million** **(0)**		**No serious mission essential capability impact** **(0)** *(Nuisance impacts on military capabilities, short duration severe weather)*

Note: 1. If the threat level is Significant or High then the nuclear and infectious biological terrorist attack consequence values are:

- **Death/Injury** (1,2,3, or 4 based on installation population, assume all personnel affected).
- **Asset/Infrastructure** (Use the total installation cost to determine a value for a nuclear attack & use a value of 1 or 0 for an infectious bio or cyber attack;
- **Mission Capability**: Depending on the installation group (e.g. 1, 2, or 3) and whether or not a redundant facility or personnel exist: Nuclear = 2 or 4. Infectious Bio: 3 or 1
- If threat level is Moderate or Low, enter values of “0” for values in all 3 columns for nuclear and infectious bio attacks.

8. Response Capability Assessments: The seventh step in the Risk Management process is to factor in the mitigating effects of existing emergency response manpower, procedures, training, equipment, and exercising to more accurately predict consequences. Per reference (NFPA 1600), this process is known as a Response Capability assessment. Table 4-8 provides Response Capability assessment criteria. Table 4-8 is based upon the response capabilities defined by the current Installation Group Designation (see Standard 3 and 12). The Response Capability assessment should be viewed as an initial, baseline assessment. Follow-on EM Capability Assessments (see below) may be used to revise the Response Capability factors in Table 4-8 as capabilities improve.

Table 4-8: Response Capability Assessment Criteria

	Response Capability Factors		
Existing Response Capabilities	**Nuclear Terrorism Attack** *(If threat level is Significant or High*	**Terrorism CBR-E Attacks** *(for all threat levels*	**Natural Hazards / Technological Hazards**
Group 1	2	4	8
Group 2	1	2	4
Group 3	0.1	1	2

9. Relative Risk Evaluation: Evaluating the risk of a specific threat and hazard to an asset is not enough. The risks to an asset from each threat and hazard need to be compared to risks to other assets in order to determine which assets should receive priority for application of additional response or mitigation capabilities (countermeasures).

The proper relative risk evaluation process involves applying each applicable threat and hazard (Table 4-2) against the critical infrastructure/assets determined in Table 4-3 and then determining the appropriate ranking factors in Tables 4-4 through 4-8 that apply to that asset and threat/hazard. Table 4-9 is consistent with the risk equations in Section 4-1. Table 4-9 must be filled out for each asset identified as strategic, operational, or mission-essential in Table 4-3. This is the eighth step in the Risk Management process.

Local threat assessments may result in a Low or Moderate level determination. However, Relative Risk Evaluations using all four threat level factors should be performed at least once in order to have sufficient time to identify/implement mitigation actions deemed necessary to defend against threats capable of causing mass casualties. Although the probability is low that a terrorist may deploy an improvised nuclear device or infectious biological agent, it is very important to conduct a relative risk evaluation for the Significant and High threat levels since the consequences of such events are extremely high. Conducting relative risk evaluations for the Significant and High threat levels will also help ensure that the Regional and Installation EM Plans are structured to effectively respond to CBRNE threats. When these higher threat level assessments are performed, consideration should be given to lowering some vulnerability values since higher FPCON anti-terrorist measures should lower some vulnerabilities.

CARVER$^{2™}$ relative worth methodology may only be used as a second check on the assessment methodology presented in this Standard since it does not rank critical assets by

strategic/operational/mission-essential military capabilities, factor in terrorist threat level and natural/technological hazard criteria, nor existing response capability mitigation factors.

Table 4-9: Relative Risk Evaluation (Example)

Asset: Computer Network Operations Center

Location: Naval Base "X"

- Installation Value: (4)
- Asset Value: (2)
- Threat Factor = Significant (2)
- Hazard Factors: Asset is at sea level, near shoreline; earthquake/tornado resistant building; close to a single perimeter fence
- Group 1 Response Capabilities

Threat/Hazard Scenarios NOTE: 4	**Critical Infrastr-ucture (CI) Factors** *(0 to 8)*	**Threat/Hazard Factors**		**Vulnerability (V) Factors** *(0.1 to 4.5)*	**Consequence (C) Factors** *(1 to 12)*	**Response Capability (RC) Factors**		**Relative Risk Factors (RRF)** NOTES 1,2,3
		T *(0.1,1, 2, 10)*	**H** *(0.1 to 12)*			**Terrorism CBRE Attacks** *(1 to 4)* **N Attack** *(0.1 to 2)*	**Natural /Tech Hazards** *(2 to 8)*	
Tropical Cyclone, Hurricane, Typhoon	6	NA	NA	NA	NA	NA	NA	NA
Tornado	6	NA	NA	NA	NA	NA	NA	NA
Storms – Rain/wind/lightning strike & Winter (Snow, Ice, Hail, Sleet, Avalanche)	6	NA	10.5	1.25	0	NA	8	0
Drought	6	NA	NA	NA	NA	NA	NA	NA
Earthquake, building/structural collapse	6	NA	4	1.25	4	NA	8	15
Tsunami	6	NA	3	1.25	4	NA	8	11.3
Volcano	6	NA	1.1	1.25	0	NA	8	0
Landslide, Mudslide	6	NA	NA	NA	NA	NA	NA	NA

Threat/Hazard Scenarios NOTE: 4	Critical Infrastr-ucture (CI) Factors (0 to 8)	Threat/Hazard Factors		Vulnerability (V) Factors (0.1 to 4.5)	Consequence (C) Factors (1 to 12)	Response Capability (RC) Factors		Relative Risk Factors (RRF) NOTES 1,2,3
		T (0.1,1, 2, 10)	H (0.1 to 12)			Terrorism CBRE Attacks (1 to 4) N Attack (0.1 to 2)	Natural /Tech Hazards (2 to 8)	
Flood, Seiche, Tidal Surge	6	NA	NA	NA	NA	NA	NA	NA
Fire (Forest, Wilderness, Urban/Structural)	6	NA	2.1	1.25	4	NA	8	7.9
Extreme Temperatures (Heat, Cold)	6	NA	0.1	1.25	0	NA	8	0
Transportation Accidents (Aircraft, Ship, Barge, Rail, Vehicle, Bus)	6	NA	2	1.25	6	NA	8	11.3
Power/Energy/Utility Failure	6	NA	2.1	1.25	1	NA	8	2
Hazardous Material spill/release	6	NA	2.5	1.25	2	NA	8	4.7
Fuel/Resource Shortage	6	NA	NA	NA	NA	NA	8	NA
Air, Water, Soil Pollution/Contamination	6	NA	0.1	NA	NA	NA	8	0
Dam/Levee Failure	6	NA	NA	NA	NA	NA	8	NA
Financial System/Banking Collapse	6	NA	0.1	1.25	2	NA	8	0.2
Communications/ Information Technology Interruptions/Loss	6	NA	2.5	1.25	2	NA	8	4.7
Intentional Release - Chemical	6	2	NA	1	6	4	NA	18
Intentional Release - Biological	6	2	NA	1.25	8	4	NA	30

Threat/Hazard Scenarios NOTE: 4	Critical Infrastr-ucture (CI) Factors (0 to 8)	Threat/Hazard Factors		Vulnerability (V) Factors (0.1 to 4.5)	Consequence (C) Factors (1 to 12)	Response Capability (RC) Factors		Relative Risk Factors (RRF) NOTES 1,2,3
		T (0.1,1, 2, 10)	H (0.1 to 12)			Terrorism CBRE Attacks (1 to 4) N Attack (0.1 to 2)	Natural /Tech Hazards (2 to 8)	
Intentional Release/Event - Radiological	6	2	NA	1	4	4	NA	12
Intentional Event - Nuclear	6	2	NA	1.25	12	2	NA	90
Intentional Event - Explosive or Incendiary	6	2	NA	1.25	5	4	NA	18.8
Intentional Event – Electromagnetic and/or Cyber	6	2	NA	2	1	4	NA	6
Sabotage	6	2	NA	1.5	4	4	NA	18
Civil Disturbance, Riot, or Mass Panic/Hysteria	6	2	NA	1.25	2	4	NA	7.5
Arson	6	2	NA	1.25	4	4	NA	15

Notes: 1. (CI) x (T or H) x (V) x [(C)/(RC)] = RRF

2. The larger the value of the asset/infrastructure, threat/hazard probability, vulnerability, and consequence factors, the higher the relative risk factor. The higher the response capability factor, the lower the consequences, and thus the lower the relative risk factor.

3. The lower the Relative Risk Factor, the lower the overall risk.

4. Hurricane/typhoons/cyclones, drought, floods/seiche/tidal surge, land/mud slides, and tornadoes are not credible hazards scenarios for this installation/asset.

Appendix 4: Risk register

Table 6: Climate risks and opportunities for NBC. The risks have been ranked based on their risk value, from high to low. Opportunities are grouped at the end of the table. Risk reference codes relate to the workshop break-out groups, where the risk was originally identified: O = Operations; F = Facilities; T = Training; and EN = Environment. Risks and opportunities have been linked to specific NBC environments (coastal or inland), where relevant, or labeled as cross-cutting.

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
F06	Incremental climate change	causes increased competition for resources	with consequences that supplies may be reduced in favour of supply to other local users	XC	1	2	10	0	0.75	5	0	1	1	8	18.75
T02 / T14	Incremental climate change	causes change in use of space	with the consequence that land available to NBC for training is restricted, with affects for operational readiness	XC	5	2	10	0	0.75	5	0	1	1	8	18.75
T25 / F04	Incremental climate change	causes increased costs	with the consequences that planned budgets may be exceeded	XC	4	2	10	0	0.5	5	0	2	0	8	12.5
F03	Warmer and drier	causes increased	with the consequence that remote training grounds and	I		2	2	2	0.5	5	1	2	2	8	12.5

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
	conditions	risk of wild fires	buildings are damaged / destroyed, and wider natural environmental damage occurs												
OP07 / F15 / F02 / F09	More frequent extreme high temperatures	causes equipment to be operating near or above critical temperature thresholds	with the consequences that critical infrastructure (e.g. IT, power & comms) may fail, impacting operations, training and readiness	XC	2	2	10	0	0.5	5	0	1	1	8	12.5
F26	More frequent heavy downpours of rain	causes erosion of inland sites	with the consequences that environmental degradation occurs and there is a risk of further ground instability	I	1	2	1	2	0.75	5	1	1	2	8	11.25
EN05 / EN10	More frequent extreme high temperatures	causes increased risk of wild fires	with the consequence that air and water quality are affected, with associated impacts for human health and social functioning	XC		2	10	1	0.25	5	1	1	1	8	10.3125

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
F27 / OP21	More frequent heavy downpours of rain	causes inundation and erosion of transportation routes	with the consequence that operations and training are disrupted and evacuation is compromised	XC	3	2	1	2	0.75	5	1	1	1	8	8.4375
OP05	More frequent extreme high temperatures	causes equipment to be operating near or above critical temperature thresholds	with the consequence that aircraft underperform	XC		2	10	0	0.5	5	0	0	1	8	6.25
OP12	More frequent extreme high temperatures	causes heat stress for personnel	with the consequence that rotation of personnel increases	XC		2	10	0	0.25	5	1	1	0	8	6.25
F01 / F24	More frequent heavy downpours of rain	cause flooding of buildings	with the consequence that staff cannot access operational, amenity and training buildings	XC	2	2	1	2	0.5	5	1	1	1	8	5.625

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
OP09	More frequent heavy downpours of rain	causes erosion of inland sites	with the consequences that land available for operations, training and transportation is reduced	I		2	1	2	0.75	5	0	1	1	8	5.625
OP18	Warmer and drier conditions	causes increased power and water needs & costs	with the consequence that mission essential services are compromised	XC	9	2	2	0	0.75	5	0	1	2	8	5.625
T04	Warmer and drier conditions	causes water scarcity	with the consequence that competition for resources with neighbouring communities increases	XC		2	2	0	0.75	5	0	1	2	8	5.625
F05	Warmer and drier conditions	causes increased power and water needs & costs	with the consequence that OPEX is increased	XC	1	2	2	0	0.75	5	0	2	0	8	3.75
F08	Warmer and drier conditions	causes pressures on future Smart Grid	with the consequence that imbalances in supply and demand occur and there is a risk of blackouts	XC		2	2	0	0.75	5	0	1	1	8	3.75

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	**Risk**
F07	Warmer and drier conditions	causes reliance on energy intensive alternatives such as desal plants	with the consequence of competition for power and OPEX is increased	XC		2	2	0	0.75	5	0	1	1	8	3.75
OP23	Extreme events	cause emergencies in the surrounding community	with the consequence that resources are diverted away from mission objectives and training needs	XC	1	2	1	2	0.5	5	0	1	1	8	3.75
EN01	Incremental climate change	cause changes in the riparian / coastal / marine environment	with the consequence that endangered species are threatened and environmental regulatory compliance is compromised	XC	2	2	10	0	0.1	5	0	2	1	8	3.75
OP19	More frequent heavy downpours of rain	causes flooding of sewer systems and lift stations	with the consequence that mission essential services are compromised	XC	3	2	1	2	0.5	5	0	1	1	8	3.75
F12	More frequent	causes flooding of underground	with the consequence that critical IT, power and water	XC		2	1	2	0.5	5	0	1	1	8	3.75

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
	heavy downpours of rain	infrastructure	supply may be affected												
OP20 / OP11	More frequent heavy downpours of rain	causes flooding of roads and airfields (with impacts for lighting)	with the consequence that mission essential services are compromised, assets are inoperable and training time is reduced	XC	4	2	1	2	0.5	5	0	1	1	8	3.75
T09 / OP15	Warmer and drier conditions	causes increased risk of wild fires	with consequences that personnel health and safety is compromised and environmental damage occurs, affecting operational readiness	I	5	2	2	2	0.25	5	1	1	1	8	3.75
F20 / OP2	Warmer and drier conditions	causes increased risk of wild fires	with the consequence that operational and training areas are inoperable (e.g. San Clemente Island), resulting in loss of training and readiness	XC	6	2	2	2	0.25	5	1	1	1	8	3.75
OP0	More frequent	causes increased	with the consequence that restrictions are imposed on	XC	5	2	10	0	0.25	5	0	0	1	8	3.125

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
8	extreme high temperatures	power needs	large users by power companies (e.g. taking ships off the grid)												
OP24 / T27	Sea level rise and higher wave surge	causes flooding and erosion (e.g. Silver Strand, Naval Outlying Landing Field, Imperial Beach)	with the consequence that assets and utilities are inoperable and / or damage / destroyed, affecting operational readiness and training	C	13	2	0.5	0.5	0.5	5	1	2	2	8	3.125
OP16	Warmer and drier conditions	causes water scarcity	with the consequence that services are curtailed and focus is placed on fire protection	XC	4	2	2	0.5	0.5	5	0	1	1	8	3.125
F16	Incremental climate change and extreme events	cause increases in the level of exposure due to lack of survey knowledge of common lines	with the consequences of impairing resilience planning	XC	1	2	1	0	0.75	5	0	1	2	8	2.8125
T13	Incremental climate	cause civilian population to	with the consequences that training days may be reduced	XC	2	2	1	0	0.75	5	0	2	1	8	2.812

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
	change and extreme events	become more risk averse	and it limits the tenants that can be brought in												5
F25 / T03	More frequent heavy downpours of rain	causing overwhelming of storm water drainage and flooding of assets	with the consequence that staff cannot access operational, amenity and training buildings	XC		2	1	2	0.75	5	0	0	1	8	2.8125
OP40	Extreme events	causes increases in fixed asset damage and growing awareness of weather- and climate-related impacts	with the consequence that insurance premiums increase (additional opex), fixed assets become un-insurable (liability) and NBC takes on unnecessary risks (liability) and financial burdens (additional opex)	XC		2	1	1	0.25	5	0	3	1	8	2.5
T06	Incremental climate change	causes changes in species behavior	with the consequence that protected species may migrate into or away from land owned and protected by NBC	XC		2	10	0	0.1	5	0	1	1	8	2.5

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
EN15	Incremental climate change	cause changes in the riparian / coastal / marine environment	with the consequence that environmental management costs increase	XC	5	2	10	0	0.1	5	0	2	0	8	2.5
EN18	Incremental climate change	cause changes in the riparian / coastal / marine environment	with the consequence that issues arise with insurance policies	XC		2	10	0	0.1	5	0	2	0	8	2.5
EN17	Incremental climate change	cause changes in the riparian / coastal / marine environment	with the consequence that legal challenges increase	XC		2	10	0	0.1	5	0	2	0	8	2.5
T10	More frequent extreme high temperatures	causes heat stress	with the consequence of loss of training days	XC		2	10	0	0.1	5	1	0	1	8	2.5
OP10	More frequent extreme high temperatures	causes heat stress for personnel	with the consequence that training time is reduced due to compliance with work / rest cycle (when temps >90 F,	XC		2	10	0	0.1	5	1	0	1	8	2.5

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
			45 mins rest for every 15 mins work)												
T17	Sea level rise	causes changes to nesting areas	with the consequences that NBC may not be able to meet the requirements of the Endangered Species Act and nesting birds may impact operations	C	1	2	10	0	0.1	5	0	1	1	8	2.5
OP36	Sea level rise and higher wave surge	causes flooding and erosion	with the consequence that transport infrastructure is damaged or destroyed	C	2	2	0.5	0.5	0.5	5	0	2	2	8	2.5
OP32	Sea level rise and higher wave surge	causes flooding and erosion	with the consequence that mission essential services are compromised (e.g. freshwater supply, sewage and power)	C	12	2	0.5	0.5	0.5	5	0	2	2	8	2.5
EN20	Sea level rise and higher wave surge	causes flooding and erosion	with the consequence that use of operational runways is compromised	C		2	0.5	0.5	0.5	5	0	2	2	8	2.5
T21	Sea level rise and higher	causes damage to utility	with the consequence that operational readiness and the	C	2	2	0.5	0.5	0.5	5	0	2	2	8	2.5

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
	wave surge	infrastructure	local environment are affected												
OP14	Warmer and drier conditions	causes increased risk of wild fires	with the consequence that protection and security is jeopardised (visibility, changing perimeters)	I		2	2	2	0.25	5	0	1	1	8	2.5
F23	Warmer and drier conditions	causes increased risk of wild fires	with the consequences that personnel health and safety is compromised from limited exit routes	I		2	2	2	0.25	5	1	0	1	8	2.5
T12	Warmer and drier conditions	causes increased risk of wild fires	with the consequence that communication routes are disrupted affecting training and operational readiness	XC	2	2	2	2	0.25	5	0	1	1	8	2.5
OP01	Warmer and drier conditions	causes increased risk of wild fires	with the consequence that training time is reduced because resources are diverted to evacuation and fire fighting	XC		2	2	2	0.25	5	0	1	1	8	2.5

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
OP04	Warmer and drier conditions	causes increased risk of wild fires	with the consequence that troop movements between installations / regions is increased	XC	1	2	2	2	0.25	5	0	1	1	8	2.5
F13	Warmer and drier conditions	causes decreased snow melt	with the consequence that water supply is reduced	XC	5	2	2	0	0.5	5	0	1	1	8	2.5
F14	Warmer and drier conditions	causes reduction in ground water	with the consequence that water supply is reduced	XC		2	2	0	0.5	5	0	1	1	8	2.5
T01	Incremental climate change and extreme events	causes movement of people	with the consequence that land available to NBC is restricted	XC		2	1	0	0.9	5	0	0	2	8	2.25
F43	Extreme events	causes supply chain disruption	with the consequence that the supply of essential goods and services	XC		2	1	0	0.75	5	0	1	1	8	1.875
F10	More	causes flooding of	with the consequence that	XC	2	2	1	2	0.5	5	0	0	1	8	1.875

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
	frequent heavy downpours of rain	backup infrastructure	backup power is at risk of failure												
EN14	More frequent heavy downpours of rain	causes flooding of historic properties	with the consequence that OPEX and CAPEX increases	XC	1	2	1	2	0.25	5	0	2	0	8	1.875
F30	Sea level rise and higher wave surge	causes flooding of underground infrastructure	with the consequences that water and power supplies fail	C	5	2	0.5	0.5	0.5	5	0	2	1	8	1.875
F31	Sea level rise and higher wave surge	causes flooding of power substation	with the consequence that the power supply fails	C	4	2	0.5	0.5	0.5	5	0	2	1	8	1.875
OP26	Sea level rise and higher wave surge	causes damage to old infrastructure (e.g. piers)	with the consequence that assets are inoperable	C	6	2	0.5	0.5	0.5	5	0	1	2	8	1.875
OP2	Sea level rise and higher	causes damage to old infrastructure	with the consequence that CAPEX is increased to replace	C	5	2	0.5	0.5	0.5	5	0	2	1	8	1.875

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
7	wave surge	(e.g. piers)	infrastructure												
OP35	Sea level rise and higher wave surge	causes flooding and erosion	with the consequence that assets need to be moved	C	1	2	0.5	0.5	0.5	5	0	2	1	8	1.875
F29	Sea level rise and higher wave surge	causes damage to waterfront facilities	with the consequences that operational readiness and training are affected	C	9	2	0.5	0.5	0.5	5	0	2	1	8	1.875
T11	Extreme events	causes a magnification of the intensity of impacts	with the consequence that critical safety thresholds may be breached	XC		2	1	0.5	0.25	5	1	1	1	8	1.40625
OP17	More frequent heavy downpours of rain	cause flooding	with the consequence that personal health and safety is compromised (e.g. Contamination in Tijuana River runoff)	XC	1	2	1	0.5	0.25	5	1	1	1	8	1.40625
F33	Sea level rise and higher wave surge	causes salt water ingress	with the consequences that corrosion of underground power and water	C		2	0.5	0	0.75	5	0	2	1	8	1.40625

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
			infrastructure occurs												
F34	Sea level rise and higher wave surge	causes increase in saline groundwater levels	with consequences of critical buildings being at operational risk (e.g. Fleet Area FLATSFAC communication building)	C	1	2	0.5	0	0.75	5	0	2	1	8	1.406 25
T31	More frequent extreme high temperatures	causes heat stress	with the consequence that personnel health and safety is jeopardised	XC		2	10	0.1	0.1	5	1	0	0	8	1.262 5
F19	Extreme events	causes increased electrical activity	with the consequences of affecting radio comms /electromagnetic spectrum	XC		2	1	0	0.5	5	0	1	1	8	1.25
EN1 6	Incremental climate change	cause changes in the riparian / coastal / marine environment	with the consequence that public scrutiny increases and support diminishes	XC	5	2	10	0	0.1	5	0	0	1	8	1.25
OP0 6	Incremental climate change	causes species migration	with the consequence that operations are affected (e.g. Landing Craft Air Cushion)	XC		2	10	0	0.1	5	0	0	1	8	1.25

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
T15	Incremental climate change and extreme events	causes impacts on the neighbouring communities	with consequences that NBC are required to further support and communicate effectively	XC		2	1	0	0.5	5	0	2	0	8	1.25
F35	Sea level rise and higher wave surge	causes flooding of low level facilities	with consequences that critical infrastructure (e.g. Emergency Operations Centre) is inoperable	C	5	2	0.5	0.5	0.5	5	0	1	1	8	1.25
F32	Sea level rise and higher wave surge	causes flooding of the sewer system	with the consequences that operations are impacted	C	3	2	0.5	0.5	0.5	5	0	1	1	8	1.25
F36	Sea level rise and higher wave surge	causes erosion of area with approach landing lights	with the consequence that aircraft cannot land	C		2	0.5	0.5	0.5	5	0	1	1	8	1.25
OP25	Sea level rise and higher wave surge	causes flooding and erosion of the Silver Strand	with the consequence that costs associated with protection increase (e.g. replenishment)	C		2	0.5	0.5	0.5	5	0	2	0	8	1.25

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
T22	Sea level rise and higher wave surge	causes flooding and erosion	with the consequence that personnel and civilian health and safety is jeopardised, with increased evacuations and decreased ability of first responders	C		2	0.5	0.5	0.25	5	2	1	1	8	1.25
OP3 7	Sea level rise and higher wave surge	causes flooding and erosion	with the consequence that access to critical areas and resources is restricted	C	1	2	0.5	0.5	0.5	5	0	1	1	8	1.25
OP3 3	Sea level rise and higher wave surge	causes flooding and erosion mobilising contaminates	with the consequence that personnel and civilian health and safety is compromised	C		2	0.5	0.5	0.25	5	1	2	1	8	1.25
F39	Sea level rise and higher wave surge	causes flooding of Runway 36	with the consequences that aircraft operations, training and readiness are affected	C		2	0.5	0.5	0.5	5	0	1	1	8	1.25
T29	Sea level rise and higher wave surge	causes flooding of low lying areas (e.g. former Spanish Bight)	with the consequences that traffic and transportation problems affect training	C	2	2	0.5	0.5	0.5	5	0	1	1	8	1.25

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
EN04	Warmer and drier conditions	causes increased risk of wild fires	with the consequence that habitats are changed and / or lost	XC	11	2	2	2	0.25	5	0	1	0	8	1.25
EN08	Warmer and drier conditions	causes changes in the riparian / coastal / marine environment	with the consequence that invasive species proliferate	XC		2	2	0	0.5	5	0	1	0	8	1.25
OP03	Warmer and drier conditions	causes increased risk of wild fires	with the consequence that ordnances are limited	XC		2	2	2	0.25	5	0	0	1	8	1.25
T05	Warmer and drier conditions	causes water scarcity	with the consequence that competition for resources will increase threatening security of supply to San Clemente Island and training / readiness	XC	1	2	2	0	0.5	5	0	0	1	8	1.25
F11	Extreme events	causes power line damage	with the consequence that power supply to remote training facilities may fail affecting training	I		2	1	0	0.75	5	0	0	1	8	0.9375

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
EN03	More frequent heavy downpours of rain	causes erosion and exposure of archaeological sites (e.g. human remains etc)	with the consequence that additional resources are needed for cultural work	XC		2	1	2	0.25	5	0	1	0	8	0.9375
OP31	Sea level rise and higher wave surge	causes flooding and erosion	with the consequence that surrounding communities are disrupted and NBC is involved in the emergency response and clean-up operations (e.g. debris removal)	C	2	2	0.5	0.5	0.25	5	1	1	1	8	0.9375
EN19	Sea level rise and higher wave surge	causes flooding and exceedance of storm water drainage systems	with the consequence that environmental regulatory compliance is compromised	C	5	2	0.5	0.5	0.25	5	0	2	1	8	0.9375
EN02	More frequent heavy downpours of rain	causes flooding, erosion, geomorphological changes and mobilisation of sediment and	with the consequence that environmental regulatory compliance is compromised	XC	8	2	1	0.5	0.1	5	1	2	1	8	0.75

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
		contaminants													
T23	Incremental climate change and extreme events	causes a need for increasing awareness	with the consequences that staff need to more training and preparation	XC	4	2	1	0	0.5	5	0	0	1	8	0.625
T24	Incremental climate change and extreme events	causes a need for more preparation	with the consequences that current warning systems and planning may not be adequate	XC		2	1	0	0.5	5	0	0	1	8	0.625
EN26	Sea level rise and higher wave surge	causes damage to coastal infrastructure (e.g. piers, berthing areas)	with the consequence that OPEX is increased due to increased maintenance requirements	C	10	2	0.5	0.5	0.5	5	0	1	0	8	0.625
T19	Sea level rise and higher wave surge	causes erosion of long shores	with the consequences that NBC may not be able to manage / prevent erosion	C		2	0.5	0	0.5	5	0	1	1	8	0.625

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
EN28 / EN29 / OP34	Sea level rise and higher wave surge	causes a change in the water table	with the consequence that contaminants are mobilised (from waste storage areas), environmental damage occurs and environmental compliance is compromised	C	3	2	0.5	0	0.25	5	1	2	1	8	0.625
T26	Sea level rise and higher wave surge	causes evacuation and a shift to mission essential only personnel	with the consequence that health and safety of those left remaining is compromised	C		2	0.5	0.5	0.25	5	1	0	1	8	0.625
OP38	Sea level rise and higher wave surge	causes flooding and erosion	with the consequence that it is difficult to maintain a perimeter around installations	C		2	0.5	0.5	0.5	5	0	1	0	8	0.625
T18	Sea level rise and higher wave surge	causes erosion of beaches	with the consequence that NBC may not fulfil beach nourishment (maybe due to costs) and therefore create conflict with neighbouring communities	C		2	0.5	0	0.5	5	0	1	1	8	0.625
F28	Sea level rise	causes limits on	with the consequences that	C	1	2	0.5	0	0.5	5	0	2	0	8	0.625

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	**Risk**
	and higher wave surge	available land	development of new training and operational facilities is constrained												
F40	Sea level rise and higher wave surge	causes flooding of Silver Strand Highway	with consequences that staff accessibility to the base and training are compromised	C	1	2	0.5	0.5	0.5	5	0	1	0	8	0.625
OP30	Sea level rise and higher wave surge	causes restrictions to naval vessel movements (e.g. not being able to clear bridge, bays)	with the consequence that training time is reduced	C		2	0.5	0.5	0.5	5	0	0	1	8	0.625
EN09	Warmer and drier conditions	causes changes in the marine layer	with the consequence that environmental conditions change for the mainland and coastal islands creating environmental management challenges for NBC	C	1	2	2	0	0.25	5	0	1	0	8	0.625
F37	Sea level rise and higher	causes increased stress on vertical operability of	with the consequences that loading and unloading of ships	C	1	2	0.5	0.5	0.1	5	1	1	1	8	0.375

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
	wave surge	quays	is affected												
F38	Sea level rise and higher wave surge	causes flooding of piers and harbors	with the consequence that operability of infrastructure is affected	C		2	0.5	0.5	0.1	5	1	1	1	8	0.375
F22	More frequent heavy downpours of rain	causes more discharge of pollution from runways and roads	with the consequence of environmental impacts on water bodies	XC		2	1	0.1	0.25	5	0	1	0	8	0.343 75
OP3 9	Sea level rise and higher wave surge	causes an expansion of sea surface area	with the consequence that the patrol area increases	C		2	0.5	0	0.5	5	0	1	0	8	0.312 5
OP2 2	Incremental climate change and extreme events	cause changes in the natural environment	with the consequence that costs associated with emergency preparedness increase (equipment, drills)	XC	7	2	1	0	0.1	5	0	1	1	8	0.25
T07	Incremental climate change and	causes erosion of sites with cultural	with the consequence that cultural resources are lost	XC		2	1	0	0.1	5	0	1	1	8	0.25

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
	extreme events	significance													
EN30	Sea level rise and higher wave surge	causes changes in the riparian / coastal / marine environment	with the consequence that environmental regulatory compliance is compromised	C	3	2	0.5	0	0.1	5	0	2	1	8	0.1875
EN25	Sea level rise and higher wave surge	causes erosion and exposure of archaeological sites	with the consequence that additional resources are needed for cultural work	C	8	2	0.5	0	0.25	5	0	1	0	8	0.15625
EN27	Sea level rise and higher wave surge	causes damage to coastal infrastructure (e.g. piers, berthing areas)	with the consequence that regulatory activities are increased	C		2	0.5	0.5	0.1	5	0	0	1	8	0.125
T20	Sea level rise and higher wave surge	causes coastal impacts	with the consequence that NBC may not fulfil the requirements of the Coastal Commission	C		2	0.5	0	0.1	5	0	1	1	8	0.125

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
EN21 / EN22 / T28	Sea level rise and higher wave surge	causes changes in the riparian / coastal / marine environment	with the consequence that protected / endangered species are threatened (e.g. Eel grass) creating environmental management challenges for NBC	C	15	2	0.5	0	0.1	5	0	1	1	8	0.125
T30	Sea level rise and higher wave surge	causes an increase in activity and noise levels	with the consequences that local communities are negatively impacted	C		2	0.5	0.5	0.1	5	0	0	1	8	0.125
OP28	Sea level rise and higher wave surge	causes species migration	with the consequence that operations are affected	C	1	2	0.5	0	0.1	5	0	0	1	8	0.0625
EN21	Sea level rise and higher wave surge	causes changes in the riparian / coastal / marine environment	with the consequence that protected / endangered species are threatened and NBC may need to review current / ongoing operational / training activities	C	3	2	0.5	0	0.1	5	0	1	0	8	0.0625
F21	More	causes heat	with the consequence of	XC	1	2	10	0.1	0.5	5	0	0	0	8	0

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
	frequent extreme high temperatures	damage asphalt runway shoulders and roads	runways and roads being inoperable												
OP13	More frequent extreme high temperatures	causes heat stress for military dogs	with the consequence that duties are not performed	XC		2	10	0	0.25	5	0	0	0	8	0
EN07	Warmer and drier conditions	causes decrease in soil moisture	with the consequence that vegetation changes and / or is lost creating environmental management challenges for NBC	XC	4	2	2	0	0.25	5	0	0	0	8	0
EN13	Warmer and drier conditions	causes water scarcity	with the consequence that water harvesting increases and water quality improves	XC	2	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP
F44	Incremental climate change	causes collation of data on fixed asset performance and environmental	with the consequence that there is a better understanding of the relationship between the two and NBC can reduce the risk posed by changing climate, by	XC		OP	OP	OP	OP	OP	OP	OP	OP	OP	OP

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
		conditions	introducing necessary control measures												
EN24	Sea level rise and higher wave surge	causes changes in the riparian / coastal / marine environment	with the consequence that wetland restoration occurs, which positively impacts water quality (through the filtration of pollutants)	C		OP	OP	OP	OP	OP	OP	OP	OP	OP	OP
EN11	Warmer and drier conditions	causes less preferable conditions for non-native wildlife (particularly on San Clemente Island)	with the consequence that invasive species decline	XC		OP	OP	OP	OP	OP	OP	OP	OP	OP	OP
EN31	Incremental climate change	causes a lack of enforced standards regarding climate change risk management and	with the consequence that NBC can position itself as a leader, setting appropriate benchmarks and approaches, and NBC's reputation is elevated	XC		OP	OP	OP	OP	OP	OP	OP	OP	OP	OP

Risk ref:	Climate driver (cause)	Process	Consequence	Cross-cutting (XC) / Coastal (C) / Inland (I)	Number of votes (sticky dots) at workshop	Critical Infrastructure (CI)	Hazard Relative Probability Value	Hazard Onset value	Critical Asset Vulnerability Value	Recognisability Value	Consequence - Installation Death or Injury	Consequence - Installation/ Asset Infrastructure	Consequence - Asset Mission Capability	Response Capability (RC)	Risk
		adaptation													
T16	Incremental climate change	cause cascading impacts on others	with the consequence that groups can learn and act on experience of others	XC	1	OP	OP	OP	OP	OP	OP	OP	OP	OP	OP
EN23	Sea level rise and higher wave surge	causes changes in the riparian / coastal / marine environment	with the consequence that opportunities for collaborative environment management arise	C		OP	OP	OP	OP	OP	OP	OP	OP	OP	OP
F42	Sea level rise	causes increase in water depth	with the consequence that less dredging is required	C		OP	OP	OP	OP	OP	OP	OP	OP	OP	OP
EN12	Warmer and drier conditions	causes a decline in vegetation cover	with the consequence that fuel build-up declines, the risk of wildfire decreases and training is unaffected	I		OP	OP	OP	OP	OP	OP	OP	OP	OP	OP

THIS PAGE HAS BEEN LEFT INTENTIONALLY BLANK

Appendix D: Fort Huachuca Vegetation-Fire-Wildlife Habitat Preliminary Report 2015

O'Connor, C., G. Garfin, Falk, D. (2015) Projected climate change impacts on vegetation, fire, and wildlife habitat at Fort Huachuca, Arizona. Preliminary Report. Issued: June 23, 2015. 34 pp.

Strategic Environmental Research and Develop Program (SERDP) Project RC-2232
Projected climate change impacts on vegetation, fire, and wildlife habitat at Fort Huachuca, Arizona

Preliminary Report
June 23, 2015

University of Arizona

Principal Investigator: Raphael Sagarin, Biosphere 2 Ocean

Report prepared by:
Christopher D. O'Connor, School of Natural Resources and the Environment
Gregg G. Garfin, School of Natural Resources and the Environment
Donald A. Falk, School of Natural Resources and the Environment

In collaboration with:
Jonathan Overpeck, Institute of the Environment
Jeremy Weiss, Institute of the Environment
Katherine Jacobs, Soil, Water, and Environmental Science
Jim Malusa, School of Natural Resources and the Environment
Anna Haworth, Acclimatise
John Firth, Acclimatise
Alastair Baglee, Acclimatise

Table of Contents

Funding Statement

This research is funded by the Strategic Environmental Research and Development Program (SERDP), an environmental science and technology program supported by the United States Department of Defense and co-administered by the Department of Energy and the Environmental Protection Agency. The goal of the program is to develop and apply innovative environmental technologies that reduce costs and environmental risks while improving efficiency and sustaining military readiness.

Executive Summary

Increasing temperatures and changing precipitation patterns over the next several decades are likely to result in a significant reduction in plant biomass in forests of the Huachuca Mountains. This reduction includes the loss of large old pine, Douglas- fir, and aspen forests from much of the upper elevation ecosystem. Smaller diameter Madrean oak woodland and shrubland species are likely to expand into formerly conifer-dominated forests. Landscape fire simulations suggest that changing climate is likely to increase the risk of high-severity fire in the short term, however the loss of biomass associated with high-severity fire and increasing occurrence of persistent drought are likely to function as negative feedbacks on fire spread, and may result in a net reduction in fire frequency over the next 50 years. Proactive fuel reduction treatments on Fort Huachuca and in conjunction with Coronado National Forest and The Nature Conservancy have potential to reduce the risk of high severity fire in and around protected Mexican Spotted Owl (MSO) breeding sites in the short term, but this protective effect is lost within 20 years without additional fuel treatments. Simulation of a second series of fuel reduction treatments 20 years into the simulation suggest that additional thinning treatments may be able to instill further protection from high-severity fire for additional decades. Fire management, either through direct fire suppression or fuel reduction treatments, does not appear to slow the rate of biomass loss or species change under the specific climate change scenario used.

Introduction

The United States Department of Defense has a footprint that touches all regions of the globe, exposing its personnel, infrastructure, and mission to a range of environmental and social conditions that are expected to worsen as a result of rapidly changing climate conditions over the next century. In response to this new reality, executive orders 13514 and 13653 instruct all agencies of the United States

Government to evaluate climate change risks and to manage these risks to promote the long term sustainability of agency missions (DoD 2014). Within in the United States, The Department of Defense operates training facilities on approximately 19 million acres (7.7 million hectares), making it the 5th largest land managing agency in the United States (Gorte et al. 2012). All federal lands are subject to environmental regulations designed to promote sustainability of managed and natural systems, with specific reference to maintenance of ecological function. As part of this mandate, emphasis is placed on protection of soil and water resources, as well as designing specific management activities to meet the needs of sensitive or threatened plant and animal species. For more than 30 years, training and operations planning and execution have incorporated environmental regulatory compliance, including a series of ecological monitoring programs developed independently among different branches of the armed services. The future of this balance between training, operations, and environmental commitments is uncertain under rapidly changing environmental conditions.

Climate change effects on the American Southwest

Over the next several decades, the southwestern United States is expected to experience a trend of warming annual mean temperatures and increasing variability in seasonal precipitation (Garfin et al. 2014). Global Climate Model (GCM) projections for the southwest region forecast a 1-4 $^{\circ}$F increase in summer and fall temperatures by the year 2050, with an increasing rate of warming nearer the end of the 21st century (Garfin et al. 2013). While changes to precipitation patterns are less certain, an increase in short-duration, high intensity winter storms and potential reduction in total winter precipitation, concurrent with a reduced number of frost-free days, suggests that late winter snowpack is likely to decline and winter-season flooding is likely to increase. The suite of available GCM projections suggest that the region along the US-Mexico Border is likely to experience the most severe temperature increases and reductions in winter precipitation in the southwest region. The effects of these rapid

changes to regional climate on vegetation, water supplies, and forest disturbances, such as wildfire and insect outbreaks, are not well understood, making the information available to landscape managers in the region insufficient for planning decisions or adaptation.

In the American Southwest warming temperatures and increased variability in seasonal precipitation are expected to be more dramatic than in other parts of the country. DoD installations in the Southwest will thus be subject to the effects of climate change sooner and to a greater degree than many other installations, over the next several decades. In support of the DoD's commitment to evaluate climate change risks and to develop strategies that promote long-term sustainability of installation missions while protecting supporting infrastructure and landscapes, we conducted a pilot study of projected climate change effects on vegetation, fire, and sensitive wildlife habitat at Fort Huachuca, Arizona.

The Huachuca Mountains landscape has been through a series of significant ecosystem changes over the past century. Permanent settlement of the region by EuroAmericans and establishment of the Fort in 1882 resulted in a permanent human footprint that influenced forest structure and function for the next 130 years. Prior to EuroAmerican settlement, forests and grasslands of the Huachuca Mountains were shaped by a frequent, typically low-severity, fire regime (Danzer 1998). Native American tribes active in the area for several thousand years probably augmented natural fire frequency and contributed to the fire-adapted species and forest types common to the region at the end of the 19th century (Danzer et al. 1996). Establishment of the Fort and additional permanent settlements in Sierra Vista resulted in an expansion of livestock grazing, road building, and resource extraction that led to an interruption of the frequent fire regime and loss of spreading surface fires (Danzer et al. 1996). These significant and lasting changes to forest management led to more than a century of increasing forest densities and changes to species distributions as a result of fire exclusion.

A legacy of fire

Fire history of the Huachuca Mountains is documented from dendrochronological records that predate the establishment of the Fort as well as from a 20th century fire atlas maintained by the Coronado National Forest (USDA Forest Service 2015) (Figure 1). Prior to 1900, surface fires typically burned at low to mixed-severity over much of the forested areas of the Huachuca Mountains at 4-8 year intervals (Danzer et al. 1996). The record of 20th century fires suggests a significant decline in fire size and frequency for more than 90 years post-settlement, after which relatively small fires continued to affect small parts of the landscape but were quickly extinguished by modern fire suppression practices (Figure 1).

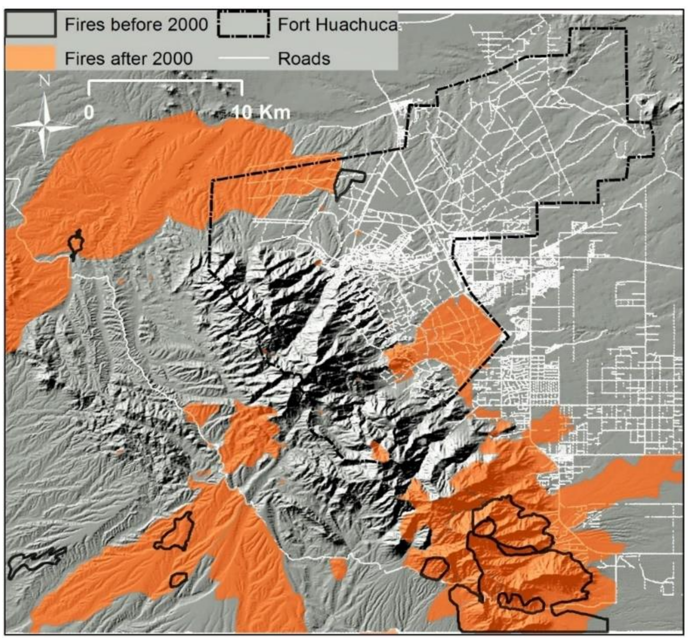


Figure 1 Coronado National Forest 20th Century Fire Atlas. Fire polygons are from the Coronado National Forest spatial database (USFS 2014). Fires before 2000 cover the 60-year period of mapped fire records from ~ 1940-2000. Fires after 2000 are current to 2014.

Over the past 30 years, the frequency and size of fires in the Huachuca Mountains has begun to increase again as human- caused ignitions, fuel loading, changes to forest species and structure, and periods of prolonged drought promote conditions for spread of high-severity fires such as the 2011 Monument Fire (Figure 2).

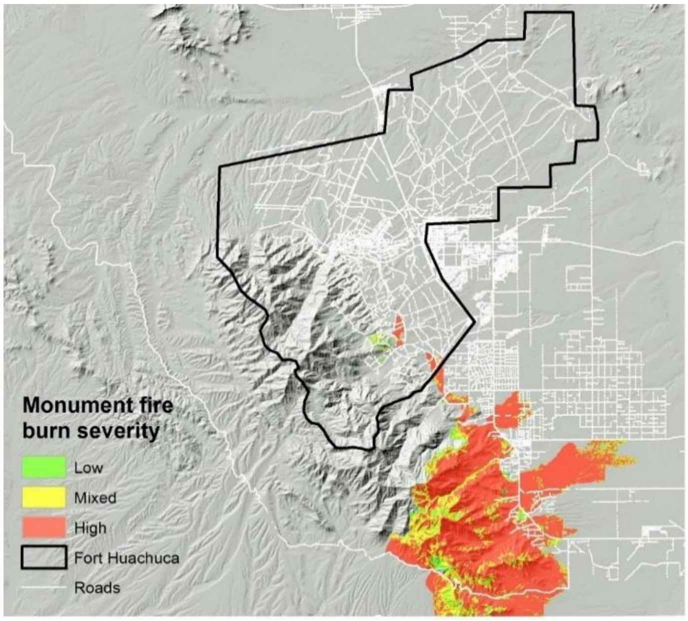


Figure 2 2011 Monument fire severity map- the largest and highest severity fire recorded in the Huachuca Mountains. Fire soil burn severity map is based on relative normalized burn ratio (rNBR) from the Monitoring Trends in Burn Severity database (MTBS 2014).

Ramifications for natural and managed landscapes

Changes to fire size and severity are already influencing management plans for forest managers on the Fort and surrounding land ownerships, as concerns about the risk of destructive forest fires to the Fort's training, operations, and stewardship missions increase. Fort Huachuca is located at a nexus of urban and natural landscapes, with a population of more than 130,000 along its eastern border, a largely unpopulated national forest with designated wilderness to the south and west, and private and state range lands to the north (Figure 3). The proximity of the Fort to an urban population that relies on the same water and electricity resources, and to a national forest with some of the highest plant and animal diversity in the region and a significant risk of damage from wildfire and flooding, make development of professional relationships with regional partners and coordination of resources a high priority.

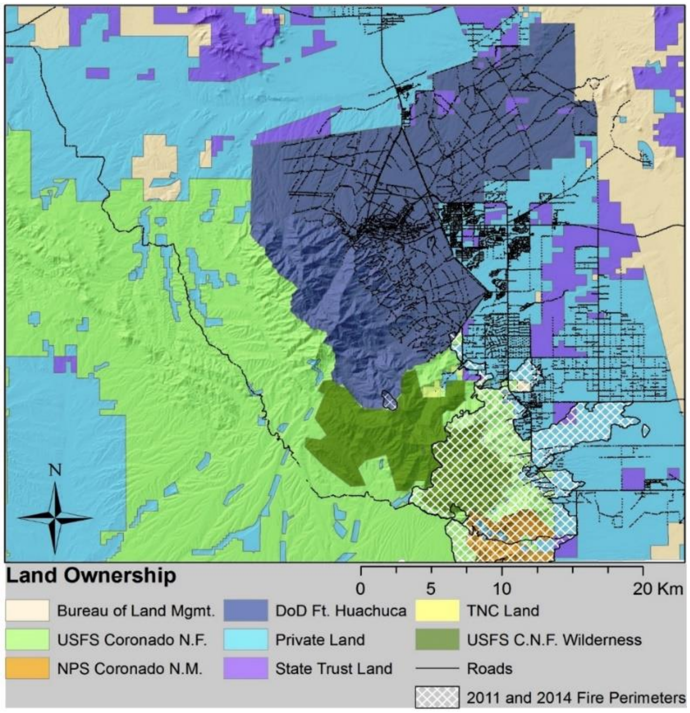


Figure 3 Multiple Land ownerships surrounding Fort Huachuca, Arizona. Mosaic of land ownerships affected by recent wildfires near the Army installation at Fort Huachuca, Arizona. The Fort shares boundaries with the USFS Coronado National Forest (Coronado N.F.), private land owners in and around the city of Sierra Vista, the State of Arizona, and the Bureau of Land Management. A fire starting in any of the above ownerships is likely to affect neighboring land owners.

Results from a study of fire risk to threatened Mexican Spotted Owl (MSO) habitat on the Fort (Hollingsworth 2014), and a series of meetings with managers from adjacent ownerships, have resulted in adoption of a proactive fire management plan by resource managers at the Fort, and initiation of forest thinning operations to mitigate near-term risks to threatened wildlife populations. Fire behavior modelling results from the 2014 study suggest that thinning operations would reduce flame lengths and mitigate other fire behavior characteristics associated with canopy fire and mortality of large trees in the near term. However, the longer-term effects of fuel modification on fire behavior, fire effects, and increasing resilience to projected warming and drying conditions in the coming decades has yet to be explored.

In addition to direct fire risk, flood damage associated with post-fire run-off is a concern for all watersheds below the Huachuca Mountains; this is evidenced by significant loss of homes and other infrastructure after monsoon rains following the 2011 Monument Fire (Youberg and Pearthree 2011). Changes to patterns of seasonal precipitation, compounded by changing fire effects, suggest that these

types of flood events, as well as non-fire-related flooding, such as the July 2014 flooding of Garden Canyon, also need to be considered by planners at the Fort and adjacent ownerships.

Previous work

In our initial meetings with Fort Huachuca Environment and Natural Resources staff, primary concerns raised were 1) the direct effects of projected changes to future climate on fire effects and vegetation communities; 2) the effectiveness of planned fuel treatments for reducing fire severity under projected climate conditions immediately after treatments and over the following decades; and 3) The longevity of the effectiveness of proposed thinning treatments for reducing fire severity and promoting resilience to changing climate, and potential benefits of additional fuel modifications in the future. Using a landscape modeling approach, we set up a series of future climate and management treatment scenarios to provide insights into each of these areas of concern.

Methods

To assess the influence of changing climate on vegetation and fire effects on Fort Huachuca and surrounding lands, we selected the FireBGCv2 simulation model (Keane et al. 2011). FireBGCv2 is a tree to landscape scale, spatially explicit, ecosystem process model designed for use in montane environments with steep ecological gradients and diverse terrain. The model essentially tracks the establishment, growth, mortality, and decay of hundreds of thousands of individual trees across a simulated landscape. Disturbance events such as fire or management operations influence the growth of trees only on the area of the landscape experiencing the disturbance. On a topographically diverse landscape such as the Huachuca Mountains, a series of different daily weather streams, modified by elevation, aspect, and topographic index are applied to adjacent vertically-stacked biomes (Figure 4). The model merges vegetation simulation components from FOREST-BGC (Running and Gower 1991) and BIOME-BGC (Running and Coughlan 1988, Running and Hunt 1993, Thornton 1998), fire initiation and spread outputs from FIRESUM (Keane et al. 1989, Keane et al. 1990), and a series of updated or

additional components that simulate weather streams and additional ecosystem processes (Keane et al. 2011).

The fire module in FireBGCv2 relies on the FIRESUM model (Keane et al. 1989) that uses a simplified, spatially explicit cell percolation algorithm to simulate fire spread, pixel-level fuel parameters to simulate fire intensity, and species-specific physiological traits to determine fire effects on individual trees. While the fire spread algorithm is simpler than that used in FLAMMAP (Finney 2006), it is also computationally more efficient and still accounts for topographic influences and wind speed and direction to simulate realistic fire progression. Vegetation parameters, fire effects, and allocation of biomass are carried out at the annual time step.

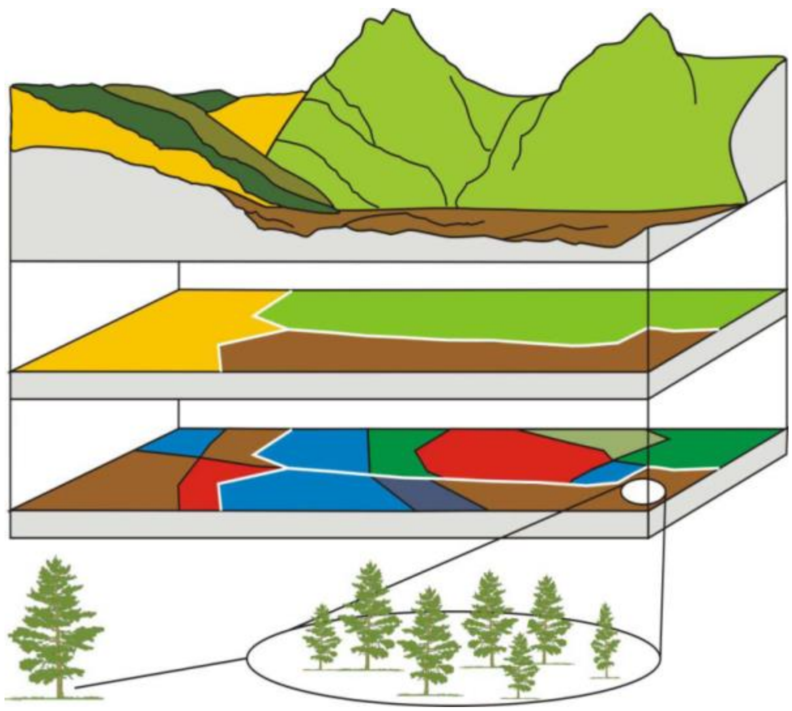


Figure 4 Structure of nested tree, plot, stand, and site layers that make up the FireBGCv2 simulation landscape. Tree, plot, and stand inputs are developed from field sampling. Site and landscape inputs are developed from a locally corrected version of the LANDFIRE national vegetation model biophysical setting layer, digital elevation model, and existing vegetation layers (LANDFIRE 2014). Site-level fire history (Danzer et al. 1996) and fuel data (Miller et al. 2003) were drawn from previous work but can also be supplied from field data or the LANDFIRE model database.

Model development and calibration

Model inputs for *species, tree*, *stand*, *fuel* and *site* files were generated from a combination of fuel plot data collected previously on Fort Huachuca, additional field-collected data, shared databases on southwestern species, and published literature on species-specific ecophysiological parameters and

fuel traits. Plot-based field data from 156 fuel plots (Miller et al. 2003) and 27 additional 500 m^2 forest inventory and age plots were used to adjust LANDFIRE vegetation maps (LANDFIRE 2014) and to develop geo-referenced species and stand databases (Figure 5). Demographic plot data provided records of tree species, diameter, height, canopy base height, and estimated tree ages. Age estimates were based on diameter-age relationships for each species developed from demographic reconstructions within plots and in the nearby Pinaleño Mountains (O'Connor 2013). Fuel parameters were developed from continuous fuels mapping estimates (Miller et al. 2003) validated with plot data from approximately 200 georeferenced photo points.

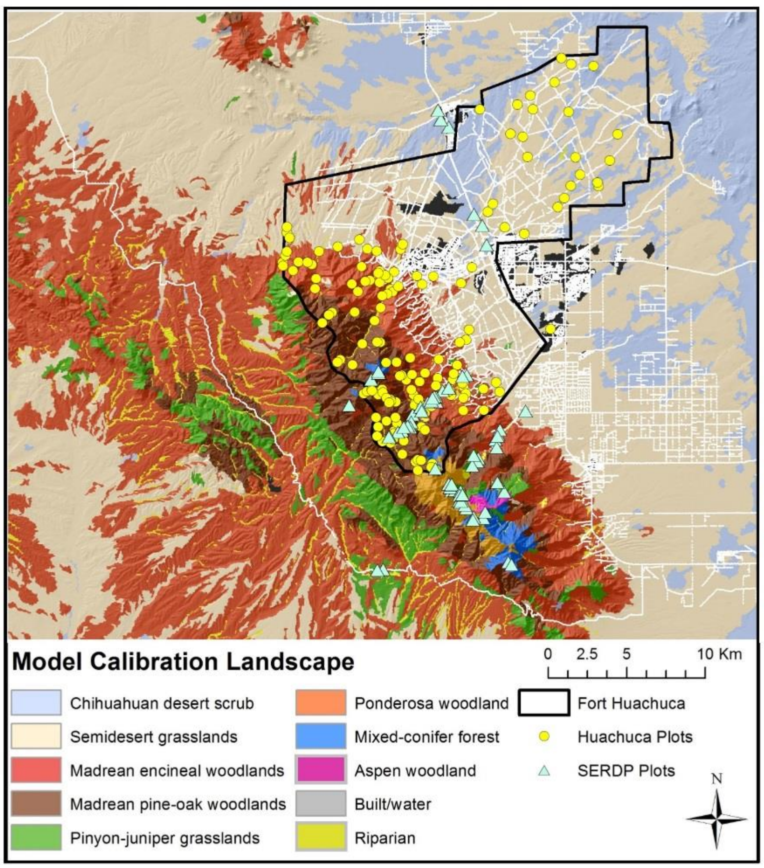


Figure 5 Distribution of ecological response units and sampling plots for model calibration. Each of 10 ERUs received a different daily weather stream based on elevation and solar exposure. Individual tree counts and size distributions from sampled plots were used to develop the simulation landscape.

We developed a database of species parameters for 16 of the most common tree, shrub, and grass components in 10 ecological response units (ERUs). The ERUs represented Chihuahuan desert scrub, semi-desert grassland, Madrean encineal woodland, Madrean pine-oak woodland, Pinyon-juniper grassland, Ponderosa woodland, Mixed-conifer forest, Aspen woodland, montane riparian woodland, and non-vegetated/developed (LANDFIRE 2014). Population-level species parameters were calculated from field-collected plot measurements and life

history descriptions. Physiological parameters and tolerances for each species were developed from a series of databases maintained by the USFS Fire Lab (Loehman et al. unpublished), the Ecological Restoration Institute at Northern Arizona University (Laughlin unpublished), as well as more general parameters published in *Silvics of North America* (Burns and Honkala 1990), and BiomeBGC input tables (White et al. 2000, Korol 2001, Hessl et al. 2004).

Individual species included for modeling were mesquite (*Vachellia densiflora*), alligator juniper (*Juniperus deppeana*), Mexican pinyon (*Pinus cembroides*), pointleaf manzanita (*Arctostaphylos pungens*), a complex of evergreen oaks (including Arizona white (*Quercus arizonica*), silverleaf (*Quercus hypoleucoides)*, netleaf (*Quercus rugose)*, and associated scrub oak(*Quercus turbinella)*), a complex of broadleaf riparian species (sycamore (*Platanus wrightii*), walnut (*Jugulas major*), bigtooth maple (*Acer grandidentatum*), cottonwood (*Populous fremontii*) and willow (*Salix gooddingii*)), velvet ash (*Fraxinus velutina*), Gambel oak (*Quercus gambelii*), Chihuahua pine (*Pinus leiophylla*), Apache pine (*Pinus engelmanii*), ponderosa/Arizona pine (*Pinus ponderosa* var. *arizonica*), white fir (*Abies concolor*), Douglas-fir (Pseudotsuga menziesii), southwestern white pine (*Pinus strobiformis*), aspen (*Populus tremuloides*), and mixed grasses. In addition to tree-form vegetation, we developed understory models for shrub-form evergreen sumac (*Rhus choriophylla*), scrub oak, manzanita, mesquite, and New Mexico locust (*Robinia neomexicana*). An extensive fuels mapping exercise was completed for the whole of the Huachuca Mountains in preparation for the 2005 FIRESCAPE project (Miller et al. 2003). This fuel assessment, generated from a combination of intensive point field sampling and continuous coverage remote-sensing imagery, provided a spatially continuous fuels input for use in fire modeling and planning for fuel modification treatments.

We populated the simulated Huachuca Mountains landscape with forest, shrubland, and grasslands representative of the 183 sample plots. The 10 ecological response units (ERUs) were further

differentiated into 46 stand types representing differences in height class and aspect. At model initiation, the Huachuca landscape had 3,141 stands differentiated by ERU, height and aspect.

Calibration

Initial calibration was based solely on vegetation succession dynamics. We modeled 300 years of vegetation growth under 20^{th} century climate with total fire suppression, to check expected species distributions along gradients of moisture, temperature, and interspecific competition. Initial species parameters were further adjusted to reflect physiological limits and competitive interactions among species that were observed in sampled plots. Multiple runs of identical initiation conditions yielded a range of results over 300 model years, because mature tree seed production and dispersal, seedling survival, and tree mortality are simulated stochastically from an independent probability distribution for each species (Keane et al. 2011). Initial species parameters were considered stable enough to move to the next calibration phase when 80% or more of modeling runs resulted in species assemblages similar to those that developed over the 20^{th} century fire exclusion period. In general, shade tolerant, dense stands of fire intolerant species were expected to dominate the landscape over a 300-year fire free interval. For example, white fir was expected to proliferate over the upper-elevation sites and to be limited by moisture at a lower elevation threshold. Shade intolerant ponderosa pine and aspen were excluded from regeneration, resulting in only large old pine and small isolated aspen stands over the 300-year simulation period.

Once species parameters were calibrated to the range of moisture and temperature conditions across the landscape, we calibrated fire dynamics based on a 400-year reconstruction of fire history on the modeled landscape (Danzer 1998). Median fire return intervals and fire sizes were used as initial *site* file fire parameters. Stand and site-level fuel depths were generated from plot measurements, and fuel model classifications and initial inputs were drawn from Rothermel (1972). Inclusion of fire in the model resulted in a slight reduction in stand biomass and a conversion from dense shade tolerant forest

types to more open fire-adapted species complexes representative of early 20th century forest conditions.

The calibration modeling weather stream was drawn from 46 years of continuous daily weather from Coronado National Monument. The single weather stream was reprojected onto the 10 Huachuca ERUs, using MT-CLIM software (Hungerford et al. 1989, Thornton and Running 1999) calibrated to the 30-year averages for total precipitation at each elevation (PRISM 2013).

Analysis area as a subset of total Simulation area

Dynamics of vegetation and fire were simulated over the entire Huachuca Mountains landscape to allow fire spread and species emigration from outside of Fort Huachuca. For analysis of fuel modification treatments and effects on Mexican Spotted Owl (MSO) habitat, maps of the simulated landscape were clipped to the specific area of concern.

Selection and processing of appropriate climate projections

Over the past decade, a number of climate projection products have become available to the general public. Deciding which of these products is appropriate for use in a given location depends on the questions being asked. Although the ability of GCMs to faithfully reproduce observed atmospheric phenomena has improved markedly over more than 40 years of development, there are still a number of considerations to keep in mind when selecting a product to use.

There is no one best model

Individual GCMs simulate components of atmospheric circulation with varying degrees of skill, depending on the assumptions implicit in the underlying mathematical representations of dynamics in the climate system (Hall 2014). Also, individual GCMs tend to be optimized for specific circulation phenomena, such as the Atlantic Meridional Overturning Circulation[1], and not for others. One approach

[1] The Atlantic Meridional Overturning Circulation (AMOC), a major current in the Atlantic Ocean, is an important component of the Earth's climate system. The AMOC transports heat energy from the tropics and the Southern Hemisphere to the North Atlantic Ocean, where the heat is transferred to the atmosphere. Changes in the AMOC could affect global climate (Survey 2012).

is to select output from a subset of GCMs, based on the ability of the GCMs to model the specific regional circulation patterns of interest using historical weather records for comparison (IPCC 2007, Brekke et al 2008, Pierce et al. 2009).

In the southwest United States one of the greatest challenges in projecting climate is accurate representation of the North American Monsoon (NAM), which is responsible for more than half of annual precipitation in parts of northern Mexico, southern Arizona and New Mexico (Adams and Comrie 1997). Careful selection of GCMs that appropriately model the climate feature of interest (in this case summer precipitation) at the regional scale when compared with historical data reduces the risk of using low-quality inputs to downscaling. In a recent evaluation of CMIP5 GCM models, the CanESM2, HadCM3, and HadGEM2-ES GCMs were found to have the lowest error rates respectively for characterizing the NAM from 1975-2005, suggesting that this GCM subset is appropriate as input for downscaling GCM output for the Southwest (Sheffield et al. 2013).

Following the selection of the appropriate GMC or GCM subset, the choice of regional downscaling method is dependent upon the heterogeneity of the landscape, the availability of weather data used to formulate downscaling relationships, the spatial resolution desired, and the length of time to be modeled. At present there are two primary methods used to downscale GCM climate projections to the finer resolution more appropriate for decision making at the regional or landscape scale. *Statistical* downscaling methods are less computationally intensive and can be more easily scaled to fine spatial resolutions of 1-10 km (0.62 -6.2 mile) grid cell size and daily to monthly time steps. *Statistical* downscaling methods rely on transfer functions, such as multivariate regression or linear modeling, which assume constant statistical relationships between global and regional climate circulation patterns (Pielke and Wilby 2012). These transfer functions are developed from historical observations, making statistical downscaling less likely to produce spurious results in the near term; however, the assumptions implicit in statistical modeling limit the use of this modeling type for realistic outputs to

short-term predictions on the order of 10-30 years, after which the assumption of constant circulation relationships may be less appropriate. *Dynamical* downscaling methods take the output from global-scale climate models and use them as inputs to regional-scale dynamical process models that emulate complex regional topography and atmospheric circulation patterns. *Dynamical* models are capable of incorporating feedback processes, such as land-atmosphere interactions, that allow new circulation patterns to develop through time. *Dynamical* downscaling is more computationally intensive, limiting the spatial and temporal resolution of publicly available products to spatial resolution of 10-50 km (6.2-15.5 miles). However, the dynamical representation of fine scale atmospheric features provides potential for much shorter time steps, allowing for detailed representation of individual convective storms at spatial scales similar to those of *statistical* methods. The implicit representation of circulation patterns at atmosphere and land surface levels and potential interactions through time make *dynamical* models more robust to long-term changes to global circulation patterns, but the small number of *dynamica*l model runs makes the use of dynamically downscaled data less statistically robust.

For either downscaling method, a higher density of weather stations and low topographic complexity improve the predictive skill of models to reproduce historical weather data. At Fort Huachuca, the high topographic complexity, relatively high density of weather stations available for generation of transfer functions, relatively short time horizon used for climate change planning, and need for daily weather inputs at high spatial resolution led us to select a publicly available s*tatistically* downscaled regional climate product with 4 km resolution. We used the Multivariate Adaptive Constructed Analogs (MACA) statistically downscaled product (Abatzoglou 2013) available for the conterminous United States (MACA 2014).

To expedite the modeling process for this pilot study, we selected the output from a single GCM. Downscaling was based on the CanESM2 GCM, one of a small group of CMIP5 models considered capable of representing the summer monsoon system of the Southwest (Sheffield et al 2013). To

capture a “worst case” scenario, we selected the most extreme IPCC Representative Concentration Pathway (RCP)[2] with a radiative forcing[3] of 8.5 W/m^2 in the year 2100. This pathway represents the radiative forcing effect of no proactive reduction of global greenhouse gas emissions (i.e., global emissions policy can be characterized as “business as usual”) and may be a conservative estimate of actual greenhouse gas concentrations later in the century.

The downscaled weather stream for the elevation of Sierra Vista and the majority of Fort Huachuca infrastructure is in general agreement with southwestern regional forecasts. Average daily winter temperatures increase 5°C (9°F) over the 21st century, with a similar trend in daily minimum and maximum temperatures (Figure 6a). Daily mean summer temperatures exhibit a slightly lower rate of increase over the next century, rising 4°C (7.2°F) on average, with greater variability in daily high temperatures and lower variability in daily low temperatures (Figure 6b).

Projections of seasonal precipitation produced by the CanESM2 model suggest little change in the total amount of winter precipitation but an increase in inter-annual variability later in the century (Figure 7). Monsoon precipitation in the CanESM2 model exhibits an increase in total volume and variability of precipitation, diverging significantly from historical trends approximately 30 years into the simulation period.

[2] Representative Concentration Pathways (RCPs) are trajectories of concentrations of greenhouse gases and pollutants resulting from human activities, including changes in land use. RCPs provide a quantitative description of concentrations of the climate change pollutants in the atmosphere over time, as well as their radiative forcing in the year 2100, expressed in units of watts per square meter (Bjørnæs 2011).

[3] Radiative forcing, expressed in units of watts per square meter, is the additional energy taken up by the Earth system due to the enhanced greenhouse effect. It can be defined as the difference in the balance of energy that enters the Earth's atmosphere (e.g., from the sun) and the amount that is returned to space (e.g., bounced back off of clouds, or re-radiated from the Earth's surface) compared to the pre-industrial balance of energy (Bjørnæs 2011).

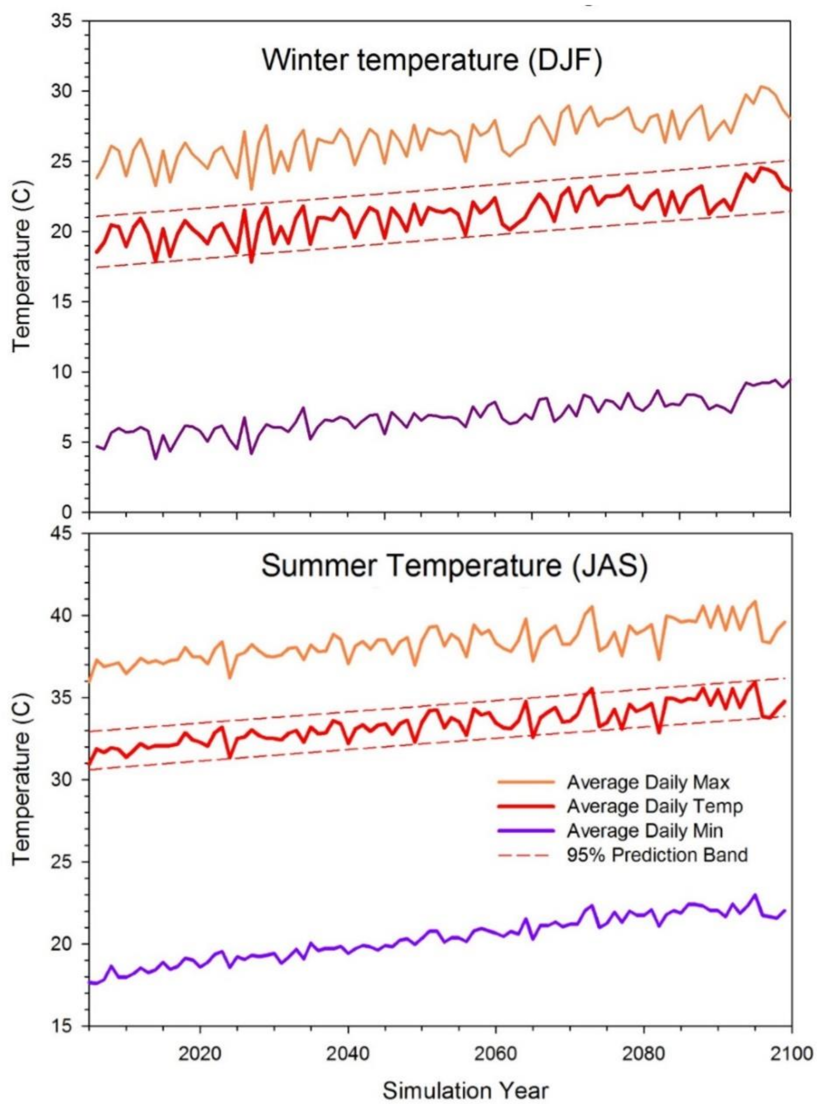


Figure 6 Projected temperature for Sierra Vista, AZ from 2005-2100 used for landscape model simulations. Winter temperature is the daily average for December, January, and February. Summer temperature is the daily average for July, August, and September. Projections are generated from the Multivariate Adaptive Climate Analogues (MACA) statistical regional downscaling of CMIP5 Can ESM2 Global Climate Model using the RCP 8.5 scenario (MACA 2014). Individual model projection is used for illustrative purposes only and is one of only three GCMs identified by Sheffield et al. (2013) capable of modeling the dynamics of the North American monsoon system with less than 30% error when compared against 30 years of historical data.

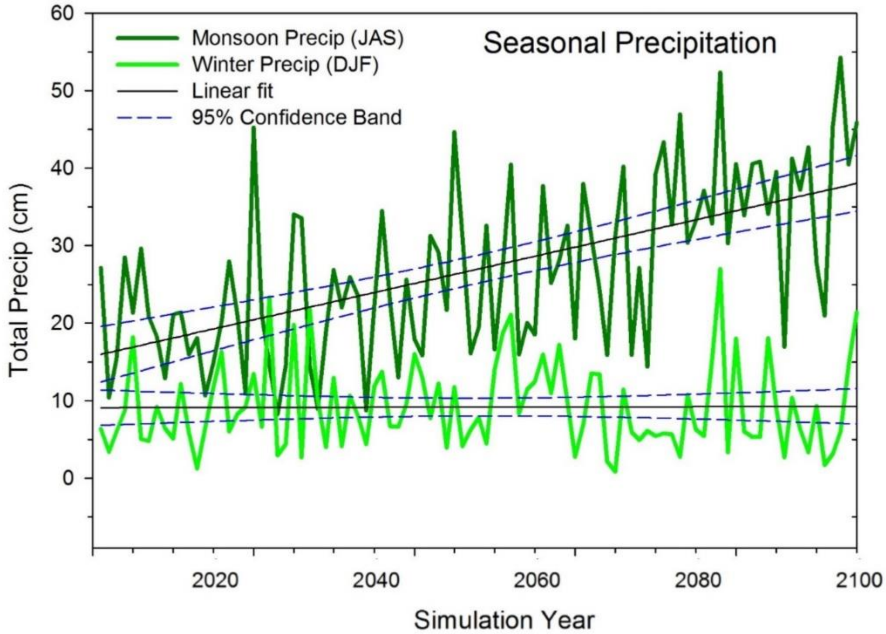


Figure 7 Projected precipitation for Sierra Vista, AZ from 2005-210.0 Methods used and time periods for downscaling are described in Figure 6.

Caution on interpreting ecological projections

For this series of simulations, we selected a single model to expedite the simulation process and to demonstrate the potential for regionally downscaled climate projections to address climate change risks to landscapes. It should be noted that while this model performs well in replicating the characteristics of historical climate and demonstrates generally agreed upon trends in future temperature and precipitation, the degree of uncertainty in the projections increases greatly at the daily or annual time step. Model agreement is highest for decadal-scale trends in seasonal temperature. Scientists are much less confident in trends in seasonal precipitation, due to the wide array of estimates among multiple GCM projections. Results from this modeling simulation, while relying on one of the best regional models for the Fort Huachuca region, should be interpreted with caution. The simulation is not a forecast, but rather it is a projection based on particular assumptions about future global greenhouse gas emissions, and is constrained by the limited statistical robustness associated with using a single GCM to make projections. Nevertheless, the changes to vegetation and fire effects simulated here may be useful for understanding trends in landscape change.

Model simulation scenarios

Following model calibration we set up a series of climate change risk scenarios for the 50-year period from 2005-2055, to assess potential effects of changing climate conditions on dominant forest species, total basal area, and stand structural class under conditions of 1) total fire suppression, 2) no fire suppression; 3) a single fuel treatment and total fire suppression ; 4) a single fuel treatment and no fire suppression; and 5) a second fuel treatment at year 20 with no fire suppression. Results from each of these scenarios were then compared to a baseline case of 50 years of landscape simulation with no fire suppression under historical climate conditions. Each modeling scenario was run 12 times to determine the trends in stochastic model outputs. Time series of the categorical variable "dominant species by biomass" were generated from the mode of the distribution of 12 values generated for each 30 m pixel. Mapped values of continuous variables "basal area" and "cumulative number of fires" used the median value of 12 model runs for each pixel of the landscape.

Fuel Treatment details

Fuel treatment scenarios assumed thinning of 100 hectares per year starting at year 1 for all proposed treatment locations on the Fort (labeled as "1" in Figure 8). In addition, this treatment scenario assumed the start of thinning of the proposed buffer zones located within Coronado National Forest at year 10 with the same thinning rate of 100 ha/year (labeled as "2" in Figure 8). Thinning prescriptions included a target basal area for forested stands between 4 and 32 m^2/ha and followed the approximately 40% reduction from current basal area measures prescribed in the MSO management plan (Hollingsworth 2014) and confirmed during consultations with the Coronado National Forest Silviculturalist (Personal Communication). The simulated thinning prescription focused on removal of trees with DBH <10 cm, although trees up to the 25 cm DBH cutting limit could be removed if necessary to reduce stand basal area to the target level. The scenario assumed 20% of slash was left behind on site.

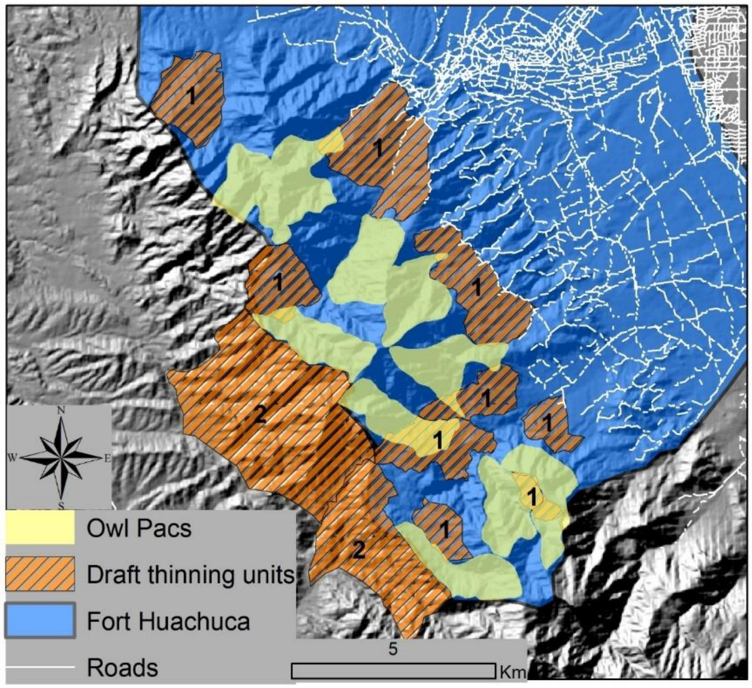


Figure 8 Proposed fuel reduction treatment locations in relation to Mexican Spotted Owl protected activity centers (PACs). Proposed fuel treatment locations on Fort Huachuca (1) and secondary treatment locations on adjacent Coronado National Forest lands (2). Thinning units are from a 2014 fire risk assessment to owl habitat (Hollingsworth 2014). Proposed thinning units were used in simulation models to assess the impact of fuel reduction on future fire and vegetation conditions under climate change.

Preliminary Results and Discussion

Landscape trends

At the landscape scale, modeling results suggest an overall decline in forest and shrubland productivity and a net loss of biomass from the system regardless of fire effects. Mortality from temperature-driven drought stress appears to be the primary change agent causing the loss of up to half of the total biomass of the system over the next 40-50 years. In the FireBGCv2 model, changes in total ecosystem carbon per unit area are used as a proxy for changes in total biomass (both live and dead plant tissues). Carbon makes up approximately 50% of the dry weight of wood. Given the assumptions of the model, weather streams, and individual species responses to changing climate, the downward trend in total carbon per unit area is strong ($R^2 = 0.867$) and significantly deviates from historical conditions within 20-25 years (Figure 9). This result also suggests that forests of the Huachuca Mountains transition from a carbon neutral system to a significant carbon source within 30 years.

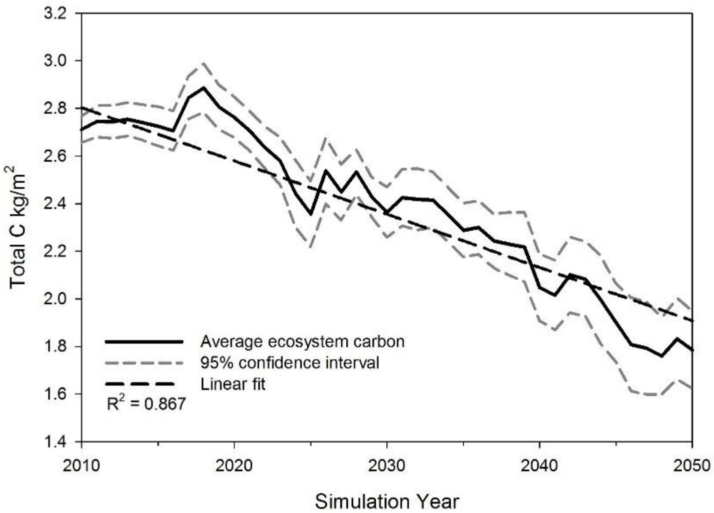


Figure 9 Change in average total carbon at the landscape scale. Trend in carbon allocation per m^2 is from 12 modeling runs assuming no management action to modify fuels or suppress fire. The general downward trend is unchanged at the landscape scale with inclusion of total fire suppression and two different fuel treatment scenarios. Results are based on the RCP 8.5 scenario of the CanESM2 GCM downscaled to 4 km using the MACA algorithm.

Dynamics of carbon allocation and loss resulting from direct fire-induced mortality and indirect climate-driven mortality, due to drought and temperate stress, suggest that at least until the 2030s, changing climate may have a greater effect on total ecosystem biomass than changes to fire effects (Figure 10). Loss of carbon due to climatic extremes exceeds that of historical conditions by 70-105% annually for the first twenty years. A switch from climate-driven carbon loss to fire driven carbon loss during the latter part of the simulation period is largely influenced by the relative reduction in available carbon. These changes to carbon allocation and fire sensitivity are further explored in the detailed spatial simulation of changes to species distributions and fire effects.

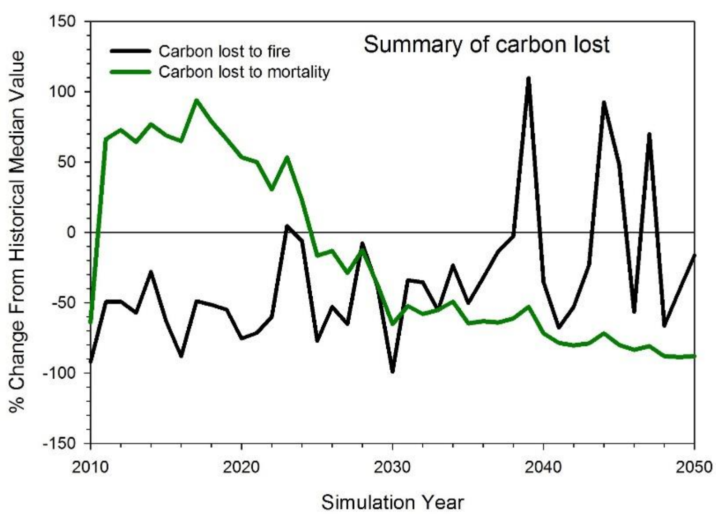


Figure 10 Loss of carbon from the Huachuca Mountains landscape as a result of fire and non-fire induced mortality. Change is scaled as a percentage of historical average annual carbon fluctuation. Values near zero represent carbon fluctuations comparable to the historical period. Simulation results assume no management action. Change is calculated from median values from 12 modeling runs of historical and projected future climate conditions

Forest response to climate change and fuel treatments in the MSO area of concern

Current vegetation types of the Huachuca Mountains remain relatively constant until the mid to late 2020s regardless of fire or thinning treatments; However, the biomass and basal area of forested ecosystems begins a steep decline near the year 2030, coinciding with the end of nearly a decade of above average winter and summer precipitation (Figure 7) and an increase in fire-cause tree mortality in simulation runs without fire suppression (Figure 11). These reductions in biomass coincide with significant and dramatic species shifts toward more drought tolerant shrubs and a complex of Madrean evergreen oaks by 2035 that remain relatively constant through the end of the simulation in 2055. While fire appears to slightly accelerate changes to vegetation type and reduction in basal area, even without fire, loss of the majority of the high elevation conifer forest and significant reduction in basal area of all species occur within 30 years under projected climate conditions (Figure 12).

Tree species diversity is not directly related to changes to species distributions and total basal area. The majority of conifer and other forest species are retained under all future scenarios albeit with reduced abundance, and often limited in spatial distribution to cool, moist riparian drainages that are buffered against the extremes of heat and drought that occur more frequently later in the simulation period (Figure 12).

Effect of thinning treatments on basal area retention and tree mortality

Fuel management treatments had little lasting effect on basal area of forests of the Huachuca Mountains. During the first ten years of model simulations under all scenarios, forests remained intact with basal areas similar to those under current and modeled historical climate conditions. Within 20 years (mid to late 2020s), future forest projections under managed and unmanaged regimes express similar uniform reduction in basal area. By year 30 (mid to late 2030s), landscapes subject to fuel treatments exhibited a trend toward greater retention of basal area in the highest elevation forests; however, by year 40 (mid to late 2040s) all simulations suggest a significant and persistent reduction in

forest basal area as climate conditions exceed the physiological limits of most of the large tree species (Figure 11).

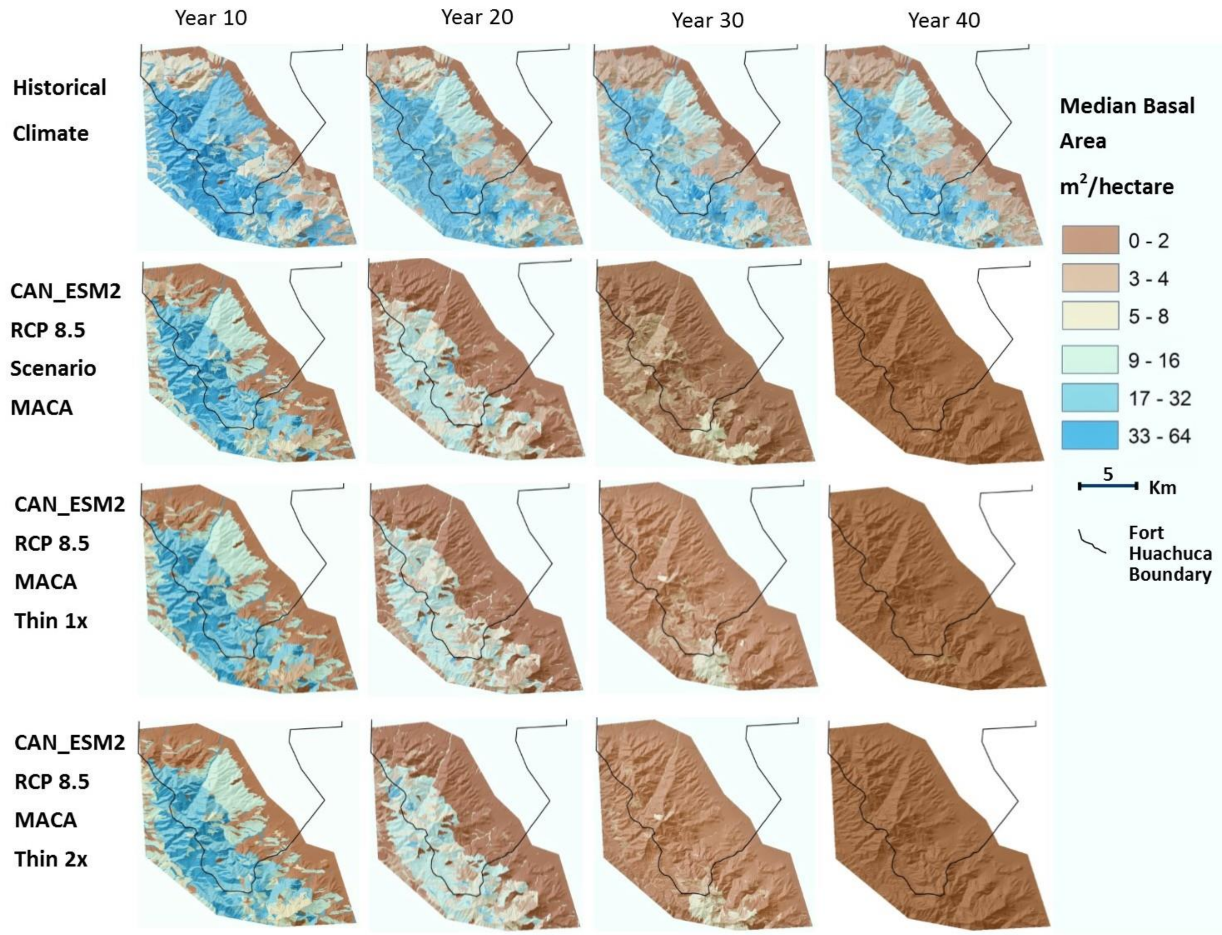


Figure 11 changes to median basal area over 40 years of model simulation. Simulations depict median basal area pixel values of 12 model runs for each simulation. Historical climate is from 1946-2010 recorded at Coronado National Monument. Future climate projections are from the CAN ESM2 GCM downscaled to 4 km using the MACA algorithm (MACA 2014). Simulations from top to bottom are: a) historical climate with no fire suppression; b) climate change with no active management; c) climate change with implementation of a single thinning treatment; and d) climate change with thinning treatments repeated at year 20.

There appears to be strong potential for climate-driven changes to vegetation even under conditions of total fire exclusion over the whole of the modeling period. While inclusion of fire in simulation models appears to accelerate the conversion of some forested areas to shrubland; fire also appears to create a more heterogeneous pattern of species, resulting in the retention of fire-adapted forest in some locations for a longer period than without fire. Thinning treatments appear to further

contribute to patterns of heterogeneity and species retention, probably resulting from reduced severity of fire effects and reduction in competition among retained trees (Figure 12).

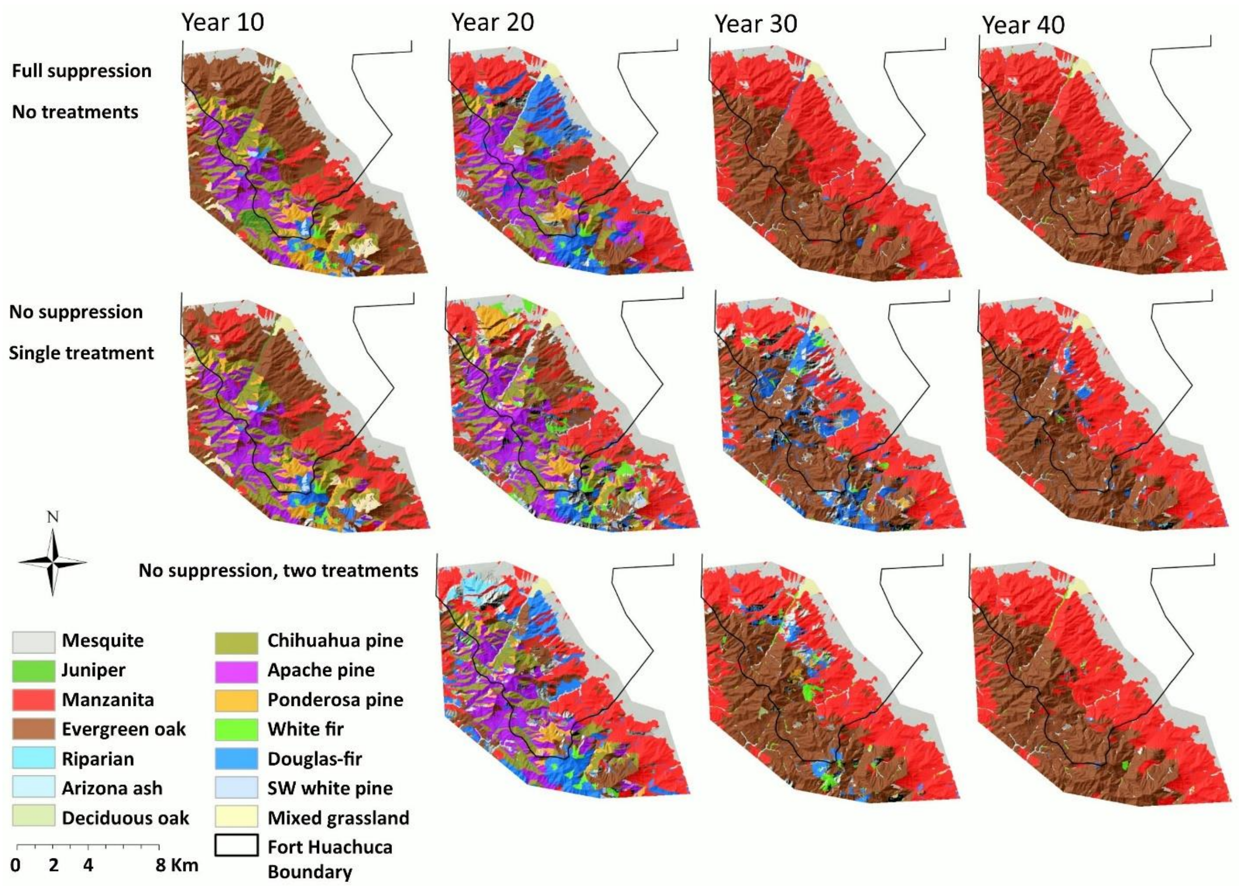


***Figure 12 Spatial distribution of dominant forest species in relation to changing climate and fuel reduction treatments**.* The full suppression scenario (a) assumes no fire occurrence over the 40-year simulation period. Results were not significantly different than the "no suppression, no treatment" scenario (no shown). Single (b) and multiple-entry (c) fuel treatments reflect conditions of no fire suppression. Species classifications represent the majority value (mode) from 12 model runs of dominant species by biomass at the 30 m pixel scale.

Fire suppression effects on forest basal area retention

Changes to forest basal area did not appear to be influenced by fire management or level of fire suppression. The rate of basal area loss was nearly identical over 40 years of simulation with or without fire (Figure 13). Fuel treatments had no significant effect on basal area retention under conditions of fire exclusion (results no shown).

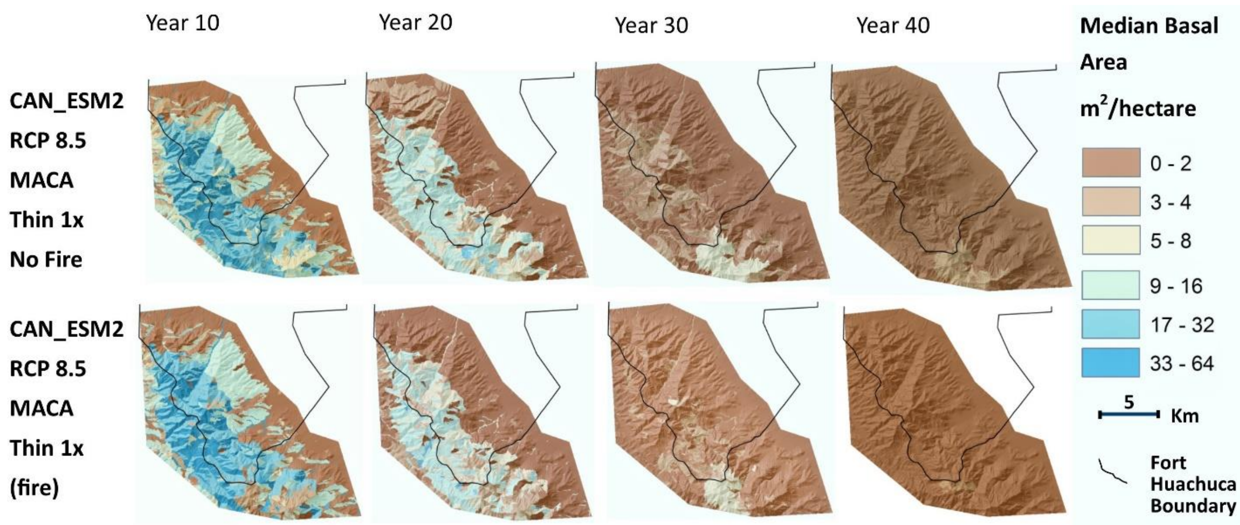


Figure 13 Projected changes to median basal area with and without fire. *Modeling methods are described in detail in Figure 11.*

Changes to fire frequency

Counter to the results from an initial 100-year simulation comparing patterns of fire under historical and projected climate, during the first forty years of future simulation with no management activity, fire frequency was slightly lower than that under historical climate conditions (Figure 14). This reduction in fire frequency may be associated with a change in the spatial distribution and availability of fuels as the spatial extent and basal area of forest species decrease through time. A related explanation for the reduction in fire frequency is the climate-driven increase in potential for high-severity fire conditions. A change from low-severity to high-severity fire regime, resulting from landscape conversion from forest to shrubland, would slow the rate of vegetation recovery and biomass accumulation. A lengthening of the post-fire period with little or patchy forest regeneration would function as a negative feedback for fire spread that depends upon a continuous surface fuel layer.

Effects of thinning treatments on the number of fires occurring in the sensitive MSO PAC area are mixed. Without active management, the pattern of fire occurrence was variable, generally resulting in a slight increase in fires in the northern part of the habitat area and decrease in fires to the south. A single intervention thinning treatment in designated parcels surrounding MSO PACS at the start of the

simulation period resulted in a pattern of fire occurrence suggesting an increase in the number of fires near the center of the MSO habitat and little change in relation to the rest of the treated and untreated areas. Inclusion of a second thinning treatment at year 20, with identical parameters to reduce basal area and canopy connectivity, resulted in a near continuous reduction in fire occurrence throughout the MSO habitat with potential to reduce fire occurrence in surrounding high-elevation forest types as well. If significant mortality of forest species is expected regardless of fire occurrence, then the changes to watersheds and runoff historically only associated with post-fire conditions may persist even with a reduction in fire occurrence.

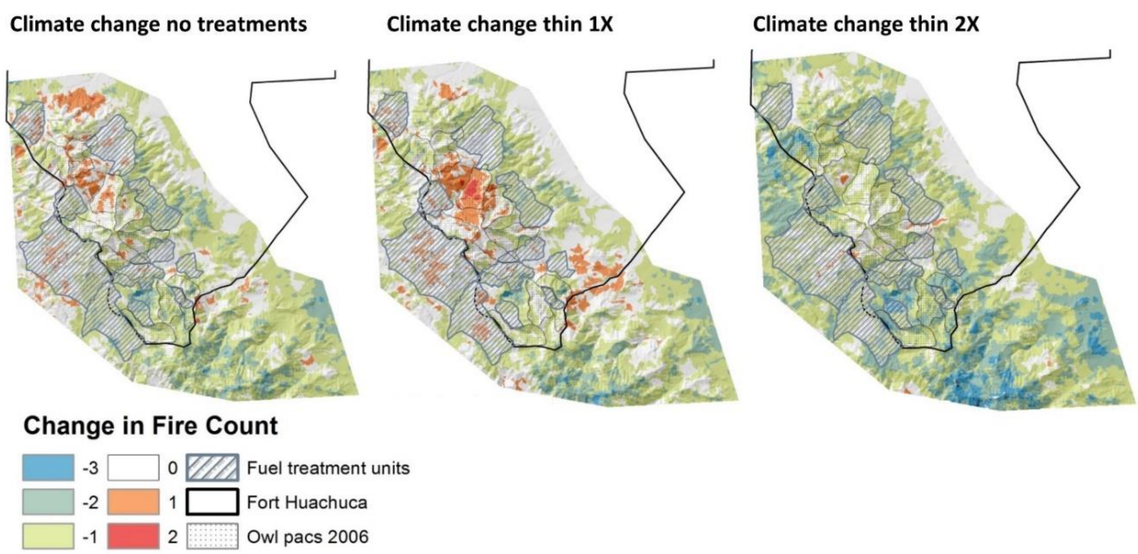


Figure 14 Projected change in fire count over 40 years of future climate in sensitive MSO habitat. Change in fire count is calculated from the median pixel value from 12 simulation runs of 20th century climate in relation to 12 simulation runs of RCP 8.5 projections. Fuel treatment units are from Hollingsworth (2014). Negative values (cool colors) represent a reduction in fire occurrence. Positive values (warm colors) represent an increase in fire occurrence.

Summary and Discussion

On the simulated landscape, forests of the Huachuca Mountains underwent significant shifts in forest biomass, species distributions, and patterns of fire over 50 years of projected future climate. Upper elevation forests, historically dominated by large mature conifers, receded to the few cool moist riparian areas at upper elevations and were largely replaced within 30 years by Madrean evergreen oak

and shrublands, historically present only at lower elevations. During the first fifty years of simulations, fire frequency decreased in comparison to fire simulations under historical climate conditions, perhaps in response to a reduction in available fuels following high-severity fire and climate conditions not conducive to forest recovery or growth of new fuels.

Fuel treatments demonstrated the potential to reduce the risk of high-severity fire in and around protected Mexican Spotted Owl breeding sites but did not appear to reduce fire frequency during the first 20 years of the model simulation. Simulation of a secondary thinning treatment at year 20 further reduced the risk of high severity fire and may also reduce the risk of fire spread into breeding sites for an additional 1-2 decades. Fire allowed to burn in conjunction with thinning treatments appeared to contribute to persistence of forest species diversity by varying the age classes and patch sizes of individual stands. The combination of thinning treatments and fire may also have served to reduce competition among trees, allowing larger, older trees to persist on the landscape longer than in forest subject to total fire exclusion. Fire management either through direct fire suppression or fuel reduction treatments did not slow the rate of landscape-scale biomass loss or changes to species distributions.

Many of the changes to forest species, loss of biomass, and fire effects from the series of landscape simulations were governed by the choice of GCM and regional downscaling method. Assumptions about temperature and precipitation inherent in the simulation weather stream underlie many of the physiological stressors and fuel curing conditions that initiated shifts in forest species and vegetation structure over the simulation period. The warm winter temperatures projected in the CanESM2 model would have reduced the number of days with snow pack and shortened the critical snow melt season. Loss of snow pack has a strong negative effect on high elevation conifer species, which are dependent upon snow melt for spring bud break and growth ring formation, and may have been one of the primary drivers of changes to forest species and loss of biomass from the ecosystem.

Under the specified climate scenario, suite of treatment prescriptions, and relying on the series of assumptions about species range distributions and environmental tolerances, the effects of changing climate appeared to overwhelm the positive influence of forest management for reducing water stress and risk of crown fire. Although the species physiological parameters developed for this landscape performed well in the calibration weather stream, actual species responses to future climate conditions are not know because little information is available regarding field or laboratory- quantified drought or heat thresholds of Madrean forest species. While this series of simulations is useful for generating research questions and testing assumptions, and was based on the best available ecological knowledge of this system, the modeling results should not be considered a prediction of actual future landscape conditions.

The FireBGCv2 model was designed for use as a research tool and not for guiding management decisions. The identification of novel changes to landscapes, such as the conversion from conifer to evergreen oak dominance of the upper elevation forests, approximately 20-30 years into a future climate scenario, is one of several unexpected model results that warrant further study. Additional work to better understand the environmental thresholds of individual species and to further examine the relative probability of conditions likely to surpass these thresholds could help to reduce the number of ecological surprises associated with future climate conditions.

The statistical methods used for regional downscaling of the CanESM2 GCM is considered most appropriate for short-term climate projections. The series of cascading changes to forest species and basal area in this series of simulations occur near the threshold of appropriate use of statistical downscaling. Additional modeling runs using a suite of different GCMs, as well as different modeling methods, such as the dynamical downscaling model being developed for the region by a different SERDP project (Castro et al. in prep) would be useful for comparing trends in climate change effects on species distributions, fire, and treatment options. Additionally, varying treatment prescriptions to further

reduce forest densities and canopy continuity as well as varying the timing of additional treatments may incrementally alter the effects of climate change on specific forests of interest such as sensitive MSO habitat.

Future Work

To examine more closely how projected future landscape conditions and climate may impact fine scale fire effects, post-fire recovery, and post-fire flooding potential, we are using a series of annual model runs to simulate the effects of a single fire event, comparable in severity to the Monument Fire, on the watersheds encompassing Garden and Huachuca Canyons. This series of scenarios will focus on immediate fire effects to vegetation, post-fire monsoon run-off, and short-term ecosystem recovery. Outputs from this series of simulations is being used in conjunction with the AGWA and KINEROS models (Smith et al. 1995, Burns et al. 2004), to perform short-term flood risk analysis for high-intensity monsoon rains, as well as an analysis of annual trends in run-off change as a result of more gradual landscape changes to vegetation. This higher spatial resolution, short duration series of studies is designed to provide more information on potential climate change, fire, and flooding risks to the two most important watersheds at Fort Huachuca.

We have completed FireBGCv2 modeling runs and have preliminary result from the AGWA and KINEROS hydrology models that are being used for calibration of simulations. We expect to have a series of new results to report in early fall of 2015.

References

Abatzoglou, J. T. 2013. Development of gridded surface meteorological data for ecological applications and modelling. International Journal of Climatology 33: 121-131.

Adams, D. K., and A. C. Comrie. 1997. The North American monsoon. Bulletin of the American Meteorological Society 78: 2197-2213.

Bjørnæs, C. 2011. A Guide to Representative Concentration Pathways. CICERO Center fior. http://www.sei-international.org/mediamanager/documents/A-guide-to-RCPs.pdf

Brekke, L. D., M. D. Dettinger, E. P. Maurer, and M. Anderson. 2008. Significance of model credibility in estimating climate projection distributions for regional hydroclimatological risk assessments. Climatic Change 89:371-394.

Burns, I., S. Scott, L. Levick, M. Hernandez, D. Goodrich, D. Semmens, W. Kepner, and S. Miller. 2004. Automated Geospatial Watershed Assessment (AGWA)-A GIS-Based Hydrologic Modeling Tool: Documentation and User Manual. ARS-1446.US Department of Agriculture, Agricultural Research Service.http://www.epa.gov/esd/land-sci/agwa/manual/01abstract/abstract.htm

Burns, R. M., B. H. Honkala. 1990. Silvics of North America: Volume 1. Conifers. USDA Forest Service Agriculture Handbook 654, Washington, DC.

Danzer, S. R., C. H. Baisan, and T. W. Swetnam. 1996. The influence of fire and land-use history on stand dynamics in the Huachua Mountains of Southeastern Arizona. US Department of Agriculture, Washington D.C. 265.

Danzer, S. 1998. Fire history and stand structure in the Huachuca Mountains of southeastern Arizona. MS. University of Arizona. Tucson, AZ. 111 p.

DoD. 2014. Climate Change Adaptation Roadmap. U.S. Department of Defense, Washington D.C. 20 p.

Finney, M.A. 2006. An overview of FlamMap fire modeling capabilities. Pages 28. in: Andrews, P. L., B. W. Butler, editors. Fuels management—how to measure success: conference proceedings. March 28-30 2006. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO. .

Garfin, G., G. Franco, H. Blanco, A. Comrie, P. Gonzalez, T. Piechota, R. Smyth, and R. Waskom. 2014. Ch. 20: Southwest. Climate Change Impacts in the United States. Pages 462-486 *In* Melillo, J. M., T. C. Richmond, and G. W. Yohe, editors. The Third National Climate Assessment, U.S. Global Change Research Program, Washington D.C.

Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy. 2013. Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment. Island Press, Washington, DC. 531 p. http://www.swcarr.arizona.edu

Gorte, R. W., C. Hardy Vincent, L. A. Hanson, and M. R. Rosenblum. 2012. Federal Land Ownership: Overview and Data. Congressional Research Service, 7-5700 R42346. Washington D.C. 27 p.

Hall, A. 2014. Climate. Projecting regional change. Science 346:1461-1462.

Hessl, A. E., C. Milesi, M. A. White, D. L. Peterson, and R. E. Keane. 2004. Ecophysiological parameters for Pacific Northwest trees. USDA Forest Service Pacific Northwest Research Station, PNW-GTR-618. Seattle, WA. 20 p.

Hollingsworth, L. 2014. Fort Huachuca 10-Year Fuels Treatment and Implementation Plan. USDA Forest Service Rocky Mountain Research Station Fire Modeling Institute, Missoula, MT. 54 p.

Hungerford, R. D., R. R. Nemani, S. W. Running, and J. C. Coughlan. 1989. MTCLIM: a mountain microclimate simulation model. USDA Forest Service Intermountain Research Station, INT-414. Ogden, UT. 55 p.

IPCC. 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. in: Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.), editor. IPCC. Geneva, Switzerland.

Keane, R. E., S. F. Arno, and J. K. Brown. 1989. FIRESUM: an ecological process model for fire succession in western conifer forests. US Dept. of Agriculture, Forest Service, Intermountain Research Station, GTR-INT-266. Ogden, UT. 79.

Keane, R. E., S. F. Arno, and J. K. Brown. 1990. Simulating cumulative fire effects in ponderosa pine/Douglas-fir forests. Ecology :189-203.

Keane, R. E., R. A. Loehman, and L. M. Holsinger. 2011. The FireBGCv2 landscape fire and succession model: a research simulation platform for exploring fire and vegetation dynamics. USDA Forest Service Rocky Mountain Research Station, RMRS-GTR-255. Ft. Collins, CO. 1-137.

Korol, R. L. 2001. Physiological attributes of 11 Northwest conifer species. USDA Forest Service, Rocky Mountain Research Station, RMRS-GTR-73. Ogden, UT. 9p.

LANDFIRE. 2014. LANDFIRE 1.1.0: Biophysical setting layer. Accessed; January 14, 2014. http://landfire.cr.usgs.gov/viewer/.

MACA. 2014. Multivariate Adaptive Constructed Analogs (MACA) Statistical Downscaling Method. University of Idaho. September 20, 2014. http://maca.northwestknowledge.net/.

Miller, J., S. Danzer, J. Watts, S. Stone, and S. R. Yool. 2003. Cluster analysis of structural stage classes to map wildland
fuels in a Madrean ecosystem. J. Env. Manage. 68:239-252.

O'Connor, C. D. 2013. Spatial and temporal dynamics of disturbance interactions along an ecological gradient. PhD Dissertation. University of Arizona. Tucson, Arizona. 204 p.

Pielke, R. A., R. L. Wilby. 2012. Regional climate downscaling: What's the point? Eos, Transactions American Geophysical Union 93: 52-53.

Pierce, D. W., T. P. Barnett, B. D. Santer, and P. J. Gleckler. 2009. Selecting global climate models for regional climate change studies. Proceedings of the National Academy of Sciences 106:8441–8446.

PRISM. 2013. PRISM Climate Group, Oregon State University. Accessed: January 14, 2013. http://prism.oregonstate.edu.

Rothermel, R. C. 1972. A mathematical model for predicting fire spread in wildland fuels. USDA Forest Service, Intermountain Forest and Range Experiment Station, Research Paper INT-115. Ogden, UT. 47.

Running, S. W., J. C. Coughlan. 1988. A general model of forest ecosystem processes for regional applications I. Hydrologic balance, canopy gas exchange and primary production processes. Ecological Modelling 42: 125-154.

Running, S. W., S. T. Gower. 1991. FOREST-BGC, a general model of forest ecosystem processes for regional applications. II. Dynamic carbon allocation and nitrogen budgets. Tree physiology 9: 147.

Running, S. W., E. R. Hunt. 1993. Generalization of a forest ecosystem process model for other biomes, BIOME-BGC, and an application for global-scale models. Scaling physiological processes: leaf to globe: 141-158.

Sheffield, J., A. P. Barrett, B. Colle, D. Nelun Fernando, R. Fu, K. L. Geil, Q. Hu, J. Kinter, S. Kumar, and B. Langenbrunner. 2013. North American Climate in CMIP5 Experiments. Part I: Evaluation of Historical Simulations of Continental and Regional Climatology*. Journal of Climate 26: 9209-9245.

Smith, R., D. Goodrich, D. Woolhiser, C. Unkrich, and V. Singh. 1995. KINEROS-A kinematic runoff and erosion model. Computer models of watershed hydrology. 697-732.

Survey, U. (2012). Atlantic meridional overturning circulation. Retrieved from: http://www.eoearth.org/view/article/150290

Thornton, P. E. 1998. Regional ecosystem simulation: combining surface-and satellite-based observations to study linkages between terrestrial energy and mass budgets. Ph. D. Dissertation. University of Montana. Missoula, MT, USA. 294.

Thornton, P. E., S. W. Running. 1999. An improved algorithm for estimating incident daily solar radiation from measurements of temperature, humidity, and precipitation. Agricultural and Forest Meteorology 93:211-228.

USDA Forest Service. 2015. USDA Forest Service Coronado National Forest GIS Data. Accessed: October 10, 2014. http://www.fs.usda.gov/detail/r3/landmanagement/gis/?cid=stelprdb5208076.

White, M. A., P. E. Thornton, S. W. Running, and R. R. Nemani. 2000. Parameterization and sensitivity analysis of the BIOME-BGC terrestrial ecosystem model: net primary production controls. Earth Interactions 4:1–85.

Youberg, A. and P. Pearthree. 2011. Post-Monument Fire floods and debris flows in the Huachuca Mountains, southern Arizona. Jan 5, 2015, 2015. http://azgeology.azgs.az.gov/article/environmental-geology/2011/09/post-monument-fire-floods-and-debris-flows-huachuca-mountains.

Appendix E: Fort Huachuca Post-Fire Flood Risk Interim Report 2 2016

O'Connor, C., Sheppard, B., Falk, D. and G. Garfin. (2016). SERDP RC-2232 Interim Report 2: Quantifying post-fire flooding risk associated with changing climate at Fort Huachuca, Arizona. Technical Report to Ft. Huachuca, Department of the Army. Issued: March 2016. 32 pp.

SERDP RC-2232 Interim Report 2: Quantifying post-fire flooding risk associated with changing climate at Fort Huachuca, Arizona.

March 1, 2016

Principal Investigator* Gregg G. Garfin, School of Natural Resources and the Environment
Principal Investigator: Raphael Sagarin, Biosphere 2 Ocean

University of Arizona

Report prepared by:
Christopher D. O'Connor, School of Natural Resources and the Environment
B. Scott Sheppard, School of Natural Resources and the Environment
Donald A. Falk, School of Natural Resources and the Environment
Gregg G. Garfin, School of Natural Resources and the Environment

In collaboration with:
Jonathan Overpeck, Institute of the Environment
Anna Haworth, Acclimatise
Jeremy Weiss, Institute of the Environment
John Firth, Acclimatise
Alastair Baglee, Acclimatise

*New Principal Investigator following the death of Dr. Sagarin

Photos from Garden Canyon, Fort Huachuca, Arizona Fall 2014. Left photo U.S. Army, right photo Christine Hass.

Contents

Funding Statement

This research is funded by the Strategic Environmental Research and Development Program (SERDP), an environmental science and technology program supported by the United States Department of Defense and co-administered by the Department of Energy and the Environmental Protection Agency. The goal of the program is to develop and apply innovative environmental technologies that reduce costs and environmental risks while improving efficiency and sustaining military readiness.

Executive summary

Monsoon flooding and associated risk to sensitive infrastructure is a significant concern for operations managers at Fort Huachuca Arizona. Projections of future climate in the southwestern United States indicate a trend of warming temperatures coupled with greater variability in seasonal rainfall. A greater understanding of the effects of these climatic changes on flooding risk, especially when coupled with changes to vegetation cover and fire activity will be essential for future planning and adaptation under a changing climate. Projected changes to high-severity fire activity in the sensitive Huachuca

Canyon watershed suggest potential for a corresponding increase in surface flow and potential peak runoff volume more than 150 times greater than current typical surface flows. A trend toward greater variability in winter runoff that includes more frequent flow pulse activity suggests that climate and fire-driven changes to surface vegetation coupled with warming winter temperatures will reduce the proportion of surface infiltration, and increase the runoff proportion of winter storm precipitation. The reduction in surface cover, exacerbated by a trend of higher fire severity, is also likely to contribute an increase in post-fire monsoon run-off over the next several decades. Results from simulations of a single rain event, based on the June 12, 2014 storm that washed out the Garden Canyon road, suggest that a similar storm centered over Huachuca Canyon has potential to result in peak flows five times that of the 2014 storm when paired with high-severity fire in the watershed. The increase in peak flows is directly associated with a trend toward larger patches of high-severity fire and loss of vegetative cover with each subsequent decade of simulation.

Introduction

Flooding and debris flows following wildfire threaten public safety and are a major cause of economic and environmental damage in the American Southwest (DeBano et al. 1998, Grimm et al. 2013, Moody et al. 2013). Changing climate conditions over the coming decades are likely to exacerbate an already heightened threat, as fuel conditions that promote high fire severity coincide with lengthening fire seasons (Westerling et al. 2003, Crimmins 2011), warming temperatures (Garfin et al. 2013), and increasing biotic stress to forests and shrublands (Allen et al. 2015, McDowell and Allen 2015). Post-fire flooding is of heightened concern in mountainous areas of the Southwest that experience high-intensity monsoon rains immediately following the late-spring fire season (Sheppard et al. 1999). Over the past two decades, flooding following large, high-severity fires has caused significant damage to infrastructure and threats to humans and wildlife in communities in Arizona, New Mexico, Colorado, and California (e.g. Miller et al. 2003, Youberg and Pearthree 2011, Grimm et al. 2013).

Wildfires can directly affect the hydrology of watersheds by reducing infiltration and evapotranspiration through the removal of vegetation and litter cover. In intact western forests, less than two percent of precipitation typically becomes surface runoff (Robichaud et al. 2000). After a high-severity fire that removes a significant amount of ground cover, water yields can increase more than 10-fold depending on the intensity and timing of the post-fire rain event (Robichaud et al. 2000, Moody et al. 2013) (Figure 1). Longevity of the changes to watershed hydrology is dependent upon the initial fire severity and time needed to regrow vegetation. In an example from a southwestern Ponderosa pine forest, the time for a watershed to return to pre-fire sediment yields ranged from three years, for low-severity fire, up to 14 years for high fire-severity (DeBano et al. 1996). The strong relationships between fire severity, watershed runoff, and time to watershed recovery, raise concerns about flooding risks posed by changing fire and climate conditions.

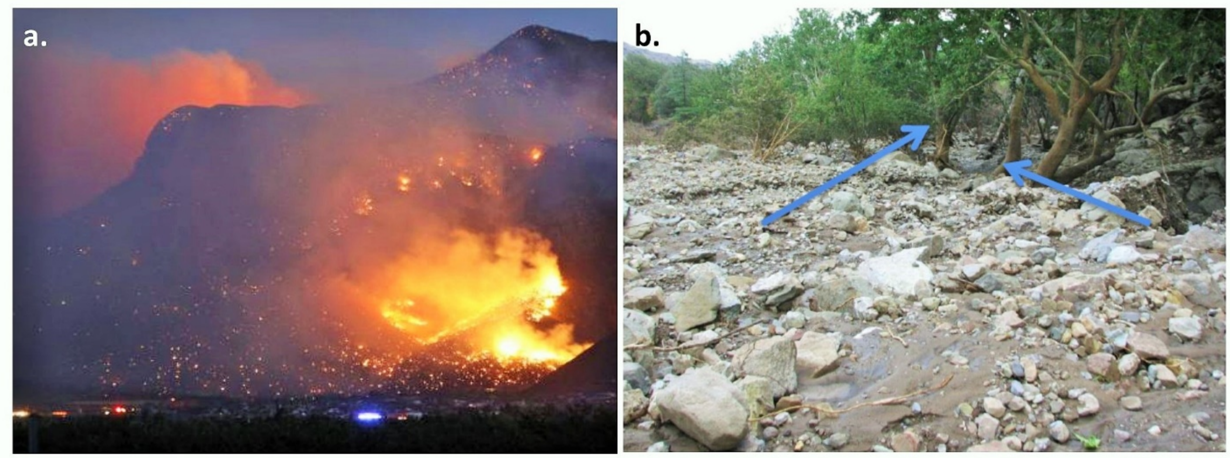


Figure 1 Monument fire in the Huachuca Mountains in 2011 (a) and post-fire debris flows in Marshall Canyon (b). Arrows in (b) identify the confluence of Marshall and Miller Creek completely infilled with rock and debris following a series of monsoon storms weeks after the Monument Fire. Photos courtesy of USA Today (a) and Ann Youberg (b).

The multiple missions of DoD lands make them especially vulnerable to risks associated with post-fire flooding, especially under accelerated and intensifying climate change. Fire and flooding risks threaten not only the primary strategic objectives of providing training and support for military operations around the globe, but also a host of secondary responsibilities such as providing employment and other economic benefits to American communities, protecting and preserving functional ecosystems, providing opportunities for recreation, and ensuring sustainable management of landscapes for military, civilian, and wildlife use.

Purpose of the Study

Following the findings of an initial study simulating climate change and fire risks to the Huachuca Mountains landscape, managers at Fort Huachuca raised additional concerns about the effects of changing climate and fire behavior on flooding risks, especially in Huachuca Canyon where there is a high concentration of historic buildings and other sensitive infrastructure. The potential for damage resulting from monsoon rains is known to operations managers at the Fort who dealt with the aftermath of a two-day monsoon-associated flooding event on July 12-13, 2014 that washed out the Garden Canyon access road; and the series of post-fire floods associated with the 2011 Monument Fire (Youberg and Pearthree 2011).

A previous hydrological modeling project at Fort Huachuca that included three other southwestern military installations fitted rainfall-runoff models to the flow regimes of ephemeral streams to characterize the current frequency and magnitude of flow events (Lyon 2013). In this work, a series of potential evapotranspiration components developed from future temperature projections (Maurer et al. 2010), suggested a decline in flow permanence, especially in higher elevation mountainous terrain as evaporative demand within the watershed increased. Results from this work suggest potential shifts toward more drought-tolerant vegetation that is in agreement with the findings

of the initial simulations of climate change effects on vegetation from part one of this study. The earlier hydrological modeling work did not incorporate projected changes to precipitation, vegetation, or fire activity, and thus could not assess future changes to seasonal surface flow patterns or peak runoff from individual high-intensity storms on landscapes affected by changing climate.

Here we use the climate change, fire, and vegetation outputs from the initial study as inputs to a series of hydrologic models to augment previous hydrological forecasting work. We use the Automated Geospatial Watershed Assessment (AGWA) modeling toolkit to assess 1) trends in seasonal run-off derived from a 40-year global climate model projection; and 2) changes to runoff from individual monsoon storms after fires of varying size and severity on a projected future landscape. This series of analyses is designed to provide information useful to managers about projected stream flow trends in Huachuca Canyon in comparison to historical hydrological patterns and a recent destructive flooding event in an adjacent watershed.

Methods

FireBGCv2

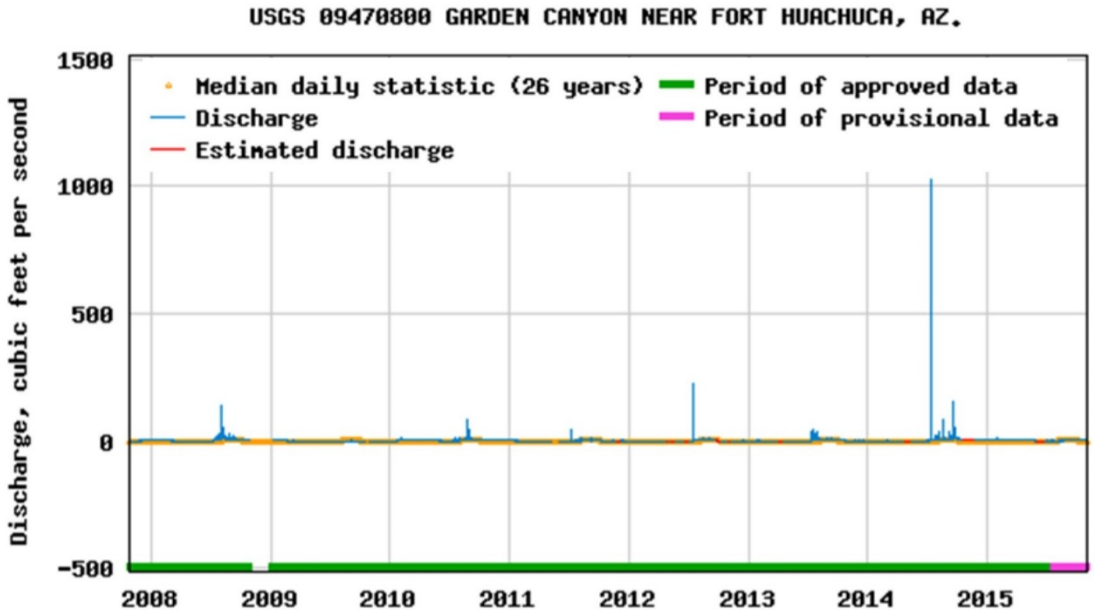
The climate scenario used to drive the vegetation and fire dynamics model underlying the hydrology modeling component was the Multivariate Adaptive Constructed Analogs (MACA) 4 km downscaled daily weather stream of the CanESM2 global climate model relative concentration pathway 8.5 (business as usual) scenario for the years 2005-2045 (Abatzoglou 2013). The CanESM2 model is appropriate for the southwest monsoon region but may over predict available future winter moisture when compared to the global climate model ensemble (Sheffield et al. 2013).

The effects of climate change on vegetation and fire in the Huachuca Mountains landscape was simulated in the FireBGCv2 modeling environment using 12 replicated model runs of 40 years with an annual time step for all output variables and maps. No fire suppression and no fuel treatments were assumed in the fire simulations. Results from vegetation change and fire activity for the Huachuca Canyon watershed were extracted from landscape-scale simulations to allow fire spread and species migration into and out of the watershed boundaries. The use of annual mapped outputs of vegetation and fire activity at 30 m resolution allowed for detailed analysis of post-fire vegetation change and fire effects that were used to adjustment watershed run-off parameters after simulated fire.

Hydrologic Modeling strategy

Development of AGWA inputs

We used the AGWA tool to develop spatial parameter estimates for the embedded SWAT (Soil Water Assessment Tool) and K2 (Kinematic Runoff and Erosion Model) hydrologic models applied to the Huachuca Canyon watershed. SWAT was used to assess how the evolving landscape, including fire, may affect runoff and water yields at seasonal time scales. The KINEROS2 model was used to assess the effects of fire severity on surface runoff associated with a single monsoon storm event following fire. Storm parameters for K2 were developed from the July 12-13, 2014 storm that caused significant road damage in the adjacent Garden Canyon watershed (Figure 2).



Daily discharge, cubic feet per second -- statistics based on 27 years of record ending 3 November 2015						
Min (1998)	25th percentile	Median	75th percentile	Nov 3, 2015	Mean	Max (2014)
0.0	0.07	0.20	0.79	0.88	0.90	1,030

Figure 2 Stream flow record at Garden Canyon. The storm event of 7/12/2014 is the largest flow rate in the 27 year record. The time series illustrates that this is an ephemeral or low flow intermittent stream. Streamflow generation is likely to be dominated by precipitation response with little to no groundwater influence.

AGWA inputs

The geospatial information necessary to run the AGWA scheme include soils, vegetative land cover, and topography (Figure 3). For both the SWAT and the K2 simulations soil data were provided by STATSGO (Natural Resources Conservation Service, USDA 2012). Topographically derived slope, flow direction, flow accumulation and watershed delineations were based on a 10 meter USGS Digital Elevation Model (DEM). Vegetative land cover was provided from annual FireBGCv2 model outputs.

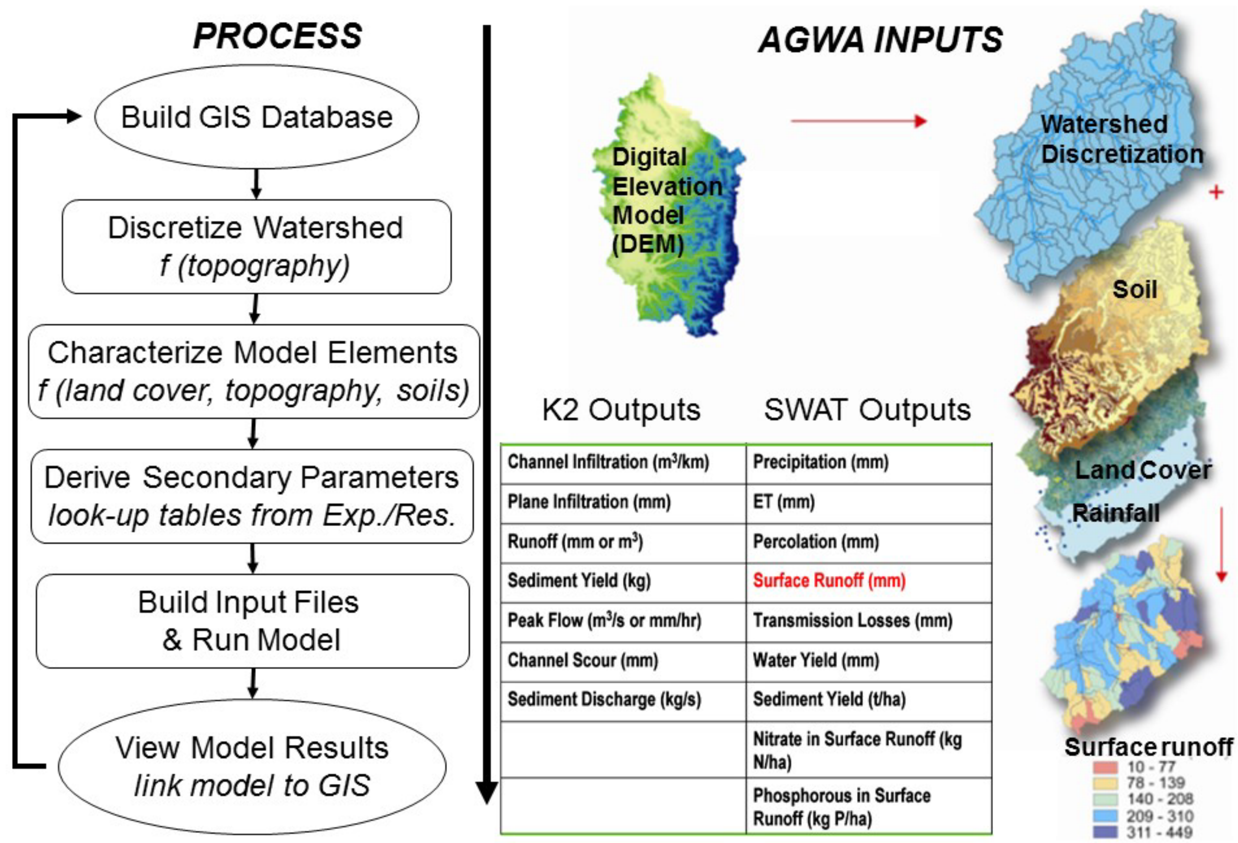


Figure 3 Conceptual design of Automated Geospatial Watershed Assessment tool (AGWA) and integrated hydrological modeling components. K2 is the Kinematic Runoff and Erosion Model and SWAT is the Soil Water Assessment Tool model. Figure adapted from D. Goodrich, USDA ARS.

Adaptation of AGWA Land cover inputs for use with FireBGCv2 outputs

FireBGCv2 vegetation categories were more specific (e.g. dominant species vs. general forest type) and complex (several basal area classes for each species) than the input parameters designed for AGWA, so we created a custom look-up table to assign Curve Numbers (CNs), hydraulic conductivities (Ks) , interception values, and hydraulic roughness (Manning's *n*) to each pixel. AGWA look up table (LUT) values were cross-walked with Fire BGCv2 outputs at each time step before and after a fire to compare the effects of individual fires at discrete time intervals across the 12 simulations (Appendix A). To account for the more complex basal area output information from FireBGCv2, CNs were rescaled in the LUT. The 45-60 m^2/ha basal area category was considered the baseline because the majority of vegetation fell within this range at the onset of the FireBGCv2 simulations. For each consecutive class below the 45-60 m^2/ha class, a reduction of 2% was made to all CN parameters in the LUTs, and a 2% increase was made for the (rare) 60-100 m^2/ha class.

Spatial distributions of dominant species by basal area were converted to curve number (CN) inputs for use in AGWA by cross-walking FireBGCv2 outputs to landscape types represented in AGWA LUTs (Appendix A). Land cover classifications were converted from continuous to discrete variables by binning basal areas into 15 m^2/ha classes. The fifth class included cells where basal area exceeded 60

m^2/ha and occupied a significantly smaller area than the other four classes. Canopy cover classes were then assigned a vegetation code and associated with hydrologic parameters in the AGWA LUT.

SWAT simulations

The SWAT model requires precipitation and temperature data as well as parameter values for Curve Numbers, infiltration rates, canopy cover, surface roughness, slope grades, and aspect. Daily precipitation and temperature data used as inputs for the FireBGCv2 model were adjusted to include leap years, and land cover inputs for SWAT were directly generated from FireBGCv2 model outputs. SWAT model runs were based on a geospatially modeled version of Huachuca Canyon soils, topography and land cover using the AGWA modeling scheme. Outputs were then compiled into a time series such that hydrologic modeling results matched the successive years of landscape modeling. Each landscape modeled was run on the same precipitation record (length and amounts) so that model 'spin ups' were identical. This analysis focused specifically on the three-month winter precipitation period from November to January and the three-month monsoon period from July to September that together account for more than 90% of the total annual precipitation in the region (Sheppard et al. 1999).

K2 simulations

The K2 model was used to investigate fire effects on watershed behavior for a single "storm of concern". This simulated event was designed to emulate the characteristics of the July 12, 2014 storm that damaged the Upper Garden roadway. The extreme run-off was the result of back to back two-year, one-hour NOAA design storms on 7/11/2014 (1.8" (4.57 cm) precipitation) and 7/12/2014 (1.6" (4.06 cm) precipitation) (Figure 4). Although the intensities of individual storms was not remarkable, the short time interval between storms resulted in saturation during the first storm and extreme run-off during the second. The frequency and intensity of monsoon rain events of this magnitude is expected to occur with greater frequency under projected future climate conditions. The July 12, 2014 rainfall event was abstracted and used to drive the K2 model using hyetograph information from Upper Garden Canyon. AGWA functionality was used to limit the extent of rainstorms to simulated burned areas to better focus on the effect of burned area hydrology.

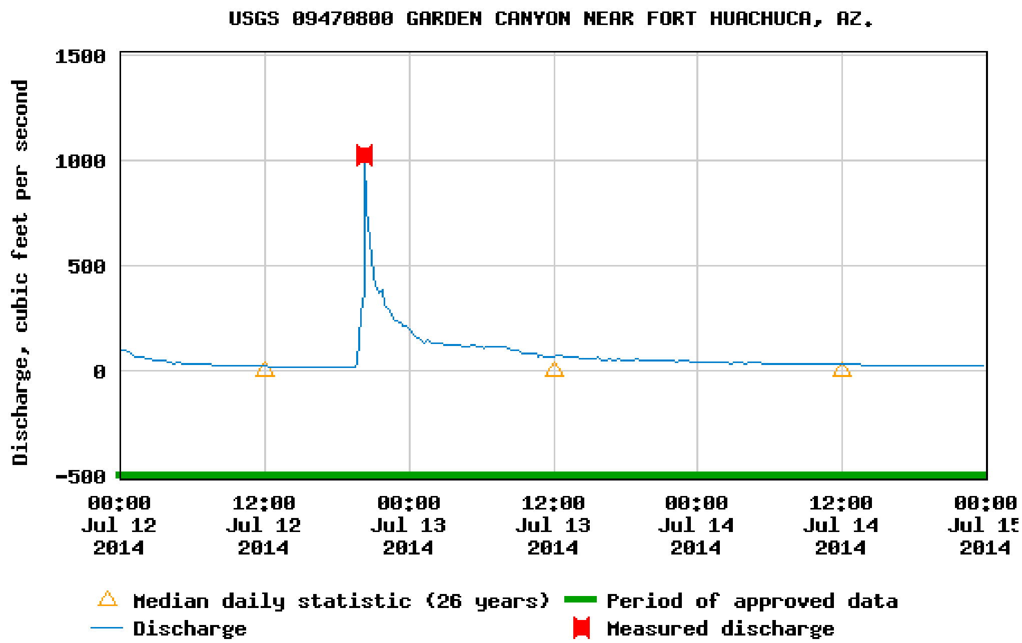


Figure 4 USGS Flow Gauge from July 12, 2014 used to calibrate modeled peak flow rates for projected future run-off. Stormflow was the result of two high-intensity, short-duration storms on consecutive days. The first storm on July 11 saturated the soil and was followed by a second storm on July 12 that caused significant run-off and damage to the Upper Garden Canyon road.

Development of burned landscape rasters for selected years

Selection of fire years for analysis was based on simulation of tree mortality the year following a fire event. By visually inspecting spatial outputs of annual tree mortality from 40 years of simulation in each of 12 FireBGCv2 simulation runs, a list of fire years within the watershed area was compiled for each simulation run. Fire severity was determined by the level of tree mortality within each 30 m^2 pixel in the fire perimeter. Fire severity was classified such that mortality of 0-10% of trees was considered unburned, 10-30% was low-severity, 30-70% was moderate-severity, and 70-100% was high-severity, approximating the descriptions of Turner et al. (1999) and Miller and Thode (2007). This product was then used as a burn severity map to update the vegetation type code in the AGWA LUT to assign hydrologic parameters to the burned area after a fire.

The 2014 rainfall/runoff event occurred on an unburned landscape, providing a useful baseline for comparison to projected changes to runoff resulting from fire effects and vegetation changes. The K2 analysis compared pre and post-fire watershed runoff to quantify changes attributable to fire effects, while holding the rain event conditions constant for both unburned and burned landscapes. An estimate of the degree of change was produced for all simulated fires provided by the FireBGCv2 model that exceeded 15% of the watershed area in the high-severity burn class. Fires with high-severity patch size less than 15% (293 ha (724 acres)) of the 1,952 ha (4,824 acre) watershed area were excluded from the analysis because a series of past studies have shown little effect of low-severity fire on watershed run-off (Cawson et al. 2012, Miller et al. 2012). To focus specifically on burned area runoff response, simulated rainfall was only applied to burned areas. This allowed for assessment of the worst case

scenario; however it also made inter-comparison of simulations less meaningful as the extent of the rainfall applied varied with fire size.

K2 precipitation and calibration

A calibration of the July 12, 2014 rain event was based on rainfall recorded at a nearby meteorological station operated by Ft. Huachuca, and the streamflow recorded by the USGS flow gauge in Garden Canyon. The calibration was designed to match the modeled peak flow rate to the observed peak flow rate (Figure 5). The infiltration rate (Ks) parameter was lowered across the simulation areas by a multiplier of 0.8 to achieve this limited calibration. The Ks parameter constant and a saturation index of 0.9 were applied to the July 12, 2014 storm parameters for K2 simulations in Huachuca Canyon.

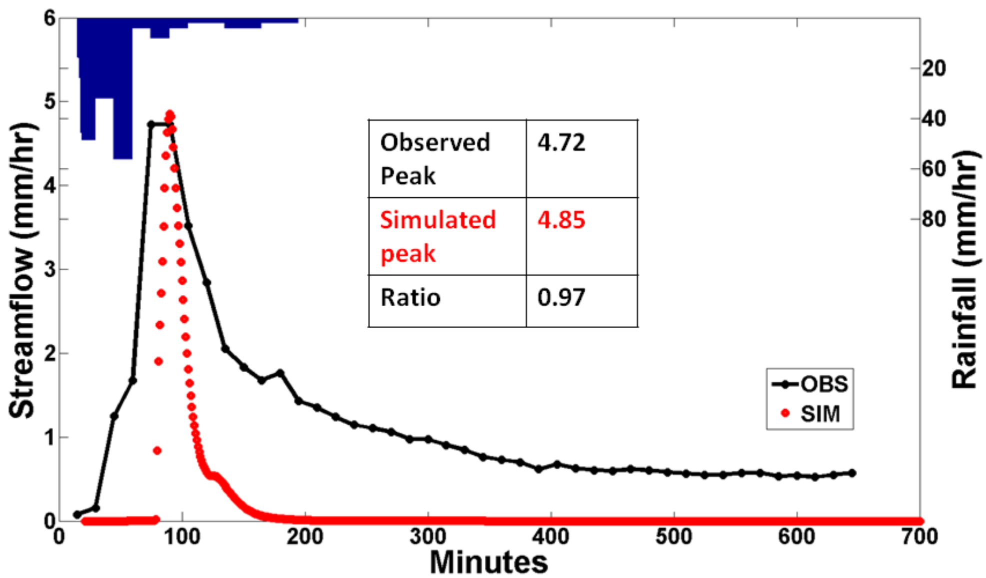


Figure 5 Observed vs. simulated streamflow for the July 12, 2014 storm in Garden Canyon. The modeled event was scaled to match the peak flow of the actual storm using a multiplier of 0.8 on the infiltration parameter. Peak flow rates are the most critical component of concern when dealing with damaging storm flows in the post fire scenario. Modeling lower-level flow for the duration of the storm would require using unrealistic surface roughness parameters; indicating that the K2 model does not capture the full suite of processes that generate stream flow in an unburned forest.

Results

Trends in fire severity and size

While individual fire size and cumulative area burned did not show a trend over the four decades of simulation, the proportion of fire area burned at high-severity increased with each decade of simulation (Figure 6).

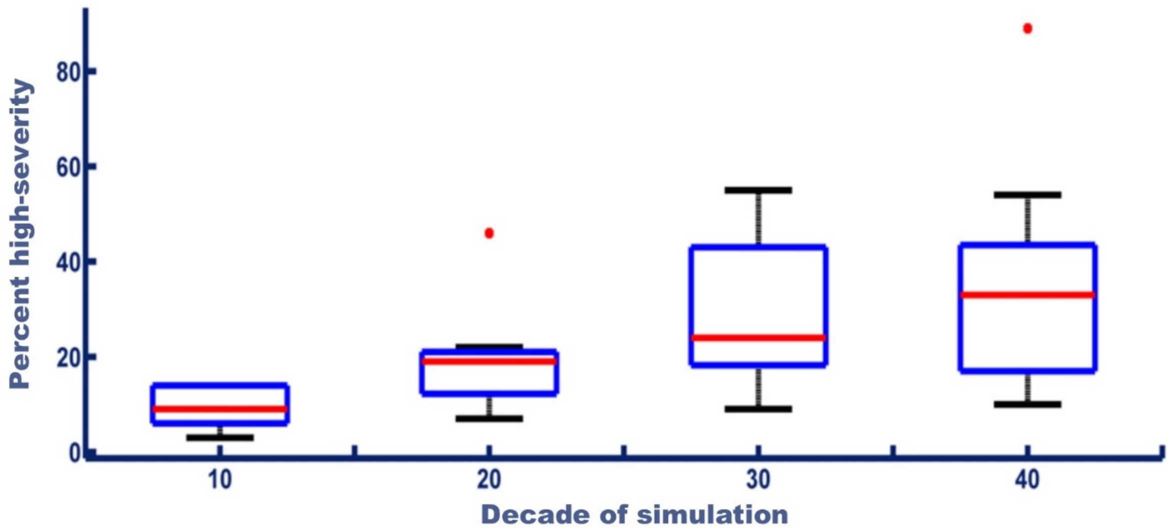


Figure 6 Simulated proportion of Huachuca Canyon watershed burning at high-severity. Mean percent area of high-severity fire (red lines) increased each decade of simulation. Variance also increased with each decade of simulation as simulated landscapes diverged from a common starting point with each decade of accumulated individual fires and resulting changes to vegetation species, structure and spatial distribution.

Factors influencing fire size

The largest simulated fires across the majority of simulations occurred during year 22 with a median high-severity component of 20%. This consistently large fire year coincided with a period of strong spring drought following several years of above average winter and summer precipitation. This pattern of widespread fires during the first severe drought following a wet period was found in the majority of independent modeling runs and is consistent with historical patterns of large fire years in the region (e.g. Swetnam and Baisan 1996, O'Connor et al. 2014).

Long-term trends in surface flow

Winter trend

Simulated winter (November-January) surface water yield increased slightly over four decades compared to the 40-year mean of discharge (Figure 7). The increase is associated with greater variability in surface flow (both minimum and maximum seasonal water yield) coincident with an increase in the variability of seasonal precipitation and the reduction in surface vegetation to buffer outflow and facilitate water infiltration. The increase in the number of above average runoff years tracks the increasing trend of large high-severity fire patches within the Huachuca Canyon watershed, even as average winter precipitation changed little in the climate change scenario used.

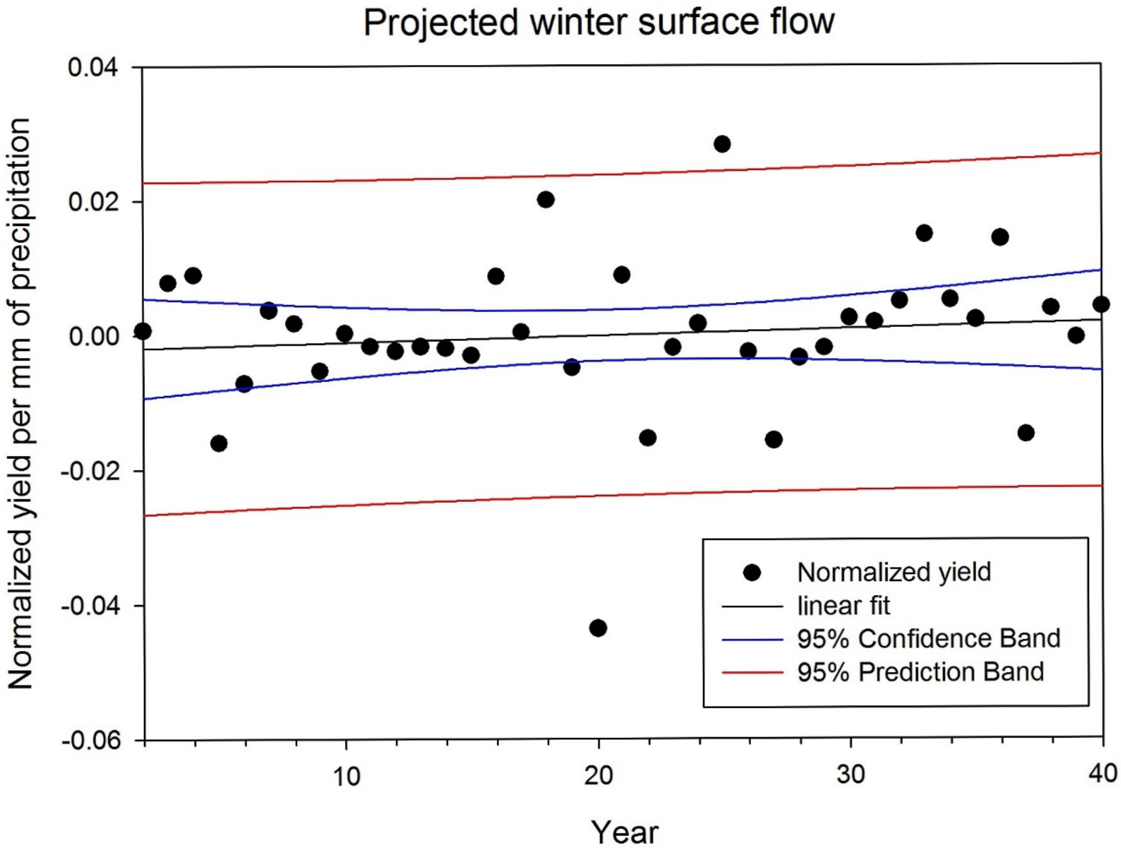


Figure 7 Winter surface flow deviation from the 40-year mean. Points are surface flow per millimeter of precipitation scaled against the 40-year mean of surface flow. Flow yield estimates are simulated at the confluence of Huachuca Canyon. Simulation period approximates climate trends and changes to vegetation and fire for the period 2005-2045.

In contrast to the slight increase in winter surface water yield, variability of year to year surface flow increased dramatically over time. This is expressed as a trend toward increasing variance in surface flow with each decade of simulation (Figure 8). The increase in flow variance is most strongly associated with years of above average water yield that become more frequent near the end of the simulation period.

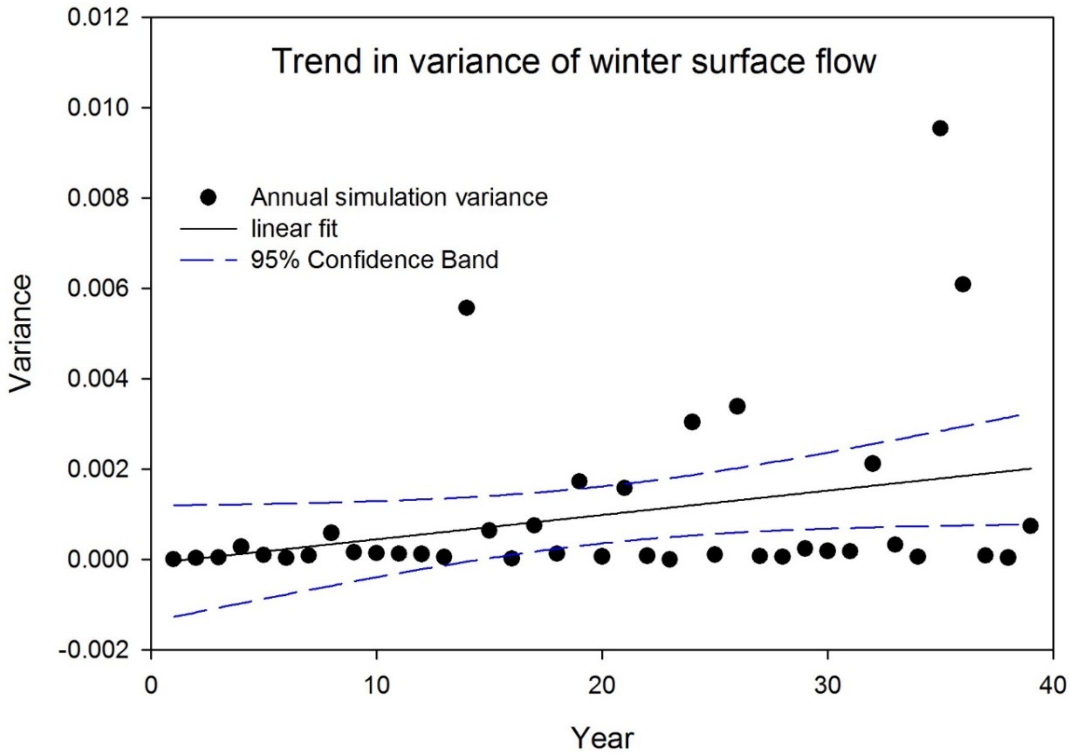


Figure 8 Simulated variance in winter surface flow. Point values represent annual variance in surface flow for 12 independent simulations. Linear fit demonstrates trend in variance and values above or below the 95% confidence interval diverge significantly from the 40-year trend.

Monsoon trend

Monsoon water yield during 40 years of simulation (July to September) was most strongly associated with post-fire flood response during years of extreme precipitation immediately following widespread fire activity. No long-term trend toward changes in summer season run-off was detected (Figure 9). Even as the density, distribution, and size of vegetation changed over the modeling period, water use efficiency, which was already low during the summer months, remained relatively unchanged. During a simulated period of extreme precipitation in year 20, coinciding with three years of extreme fire behavior, peak summer surface yield reached up to 16% of total precipitation, an amount approximately eight times the average seasonal surface yield.

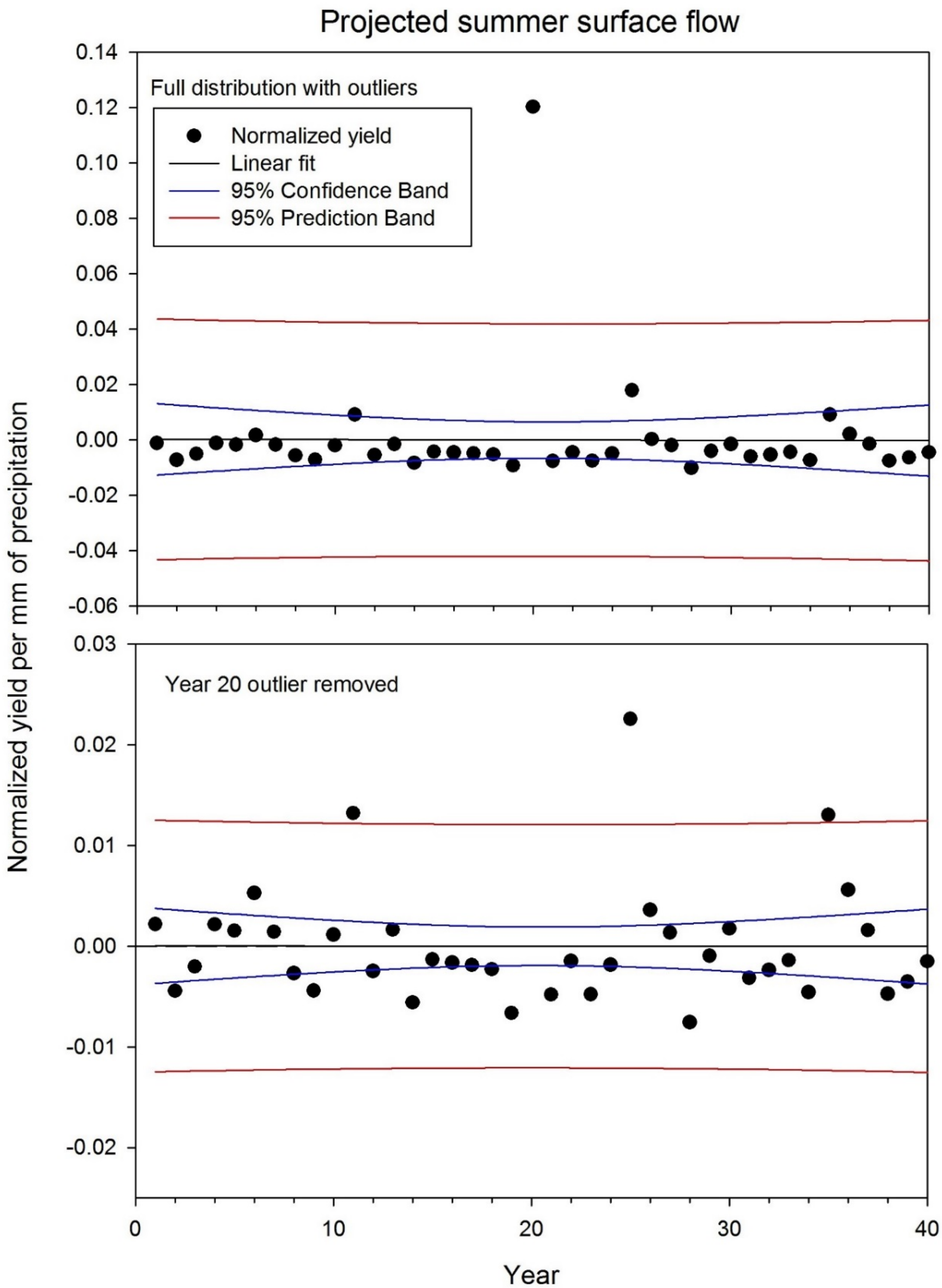


Figure 9 Trend in summer surface flow at Huachuca Canyon, AZ. Points are surface flow values normalized to the 40-year mean of water yield. Values outside of the 95% confidence bands indicate extreme run-off in response to high-severity fire (top figure) and monsoon failure (bottom figure). Flow yield estimates are simulated at the confluence of Huachuca Canyon. Simulation period approximates climate trends and changes to vegetation and fire for the period 2005-2045.

Variability of monsoon surface flow remained unchanged over the simulation period (Figure 10). This lack of change may be more a function of the typical flashy summer run-off that appears unlikely to change in the future. The single annual high-flow event at mid-simulation is the only event that significantly increased the variance of summer surface flow. This event had little effect on the long-term trend of stable variance over the simulated period.

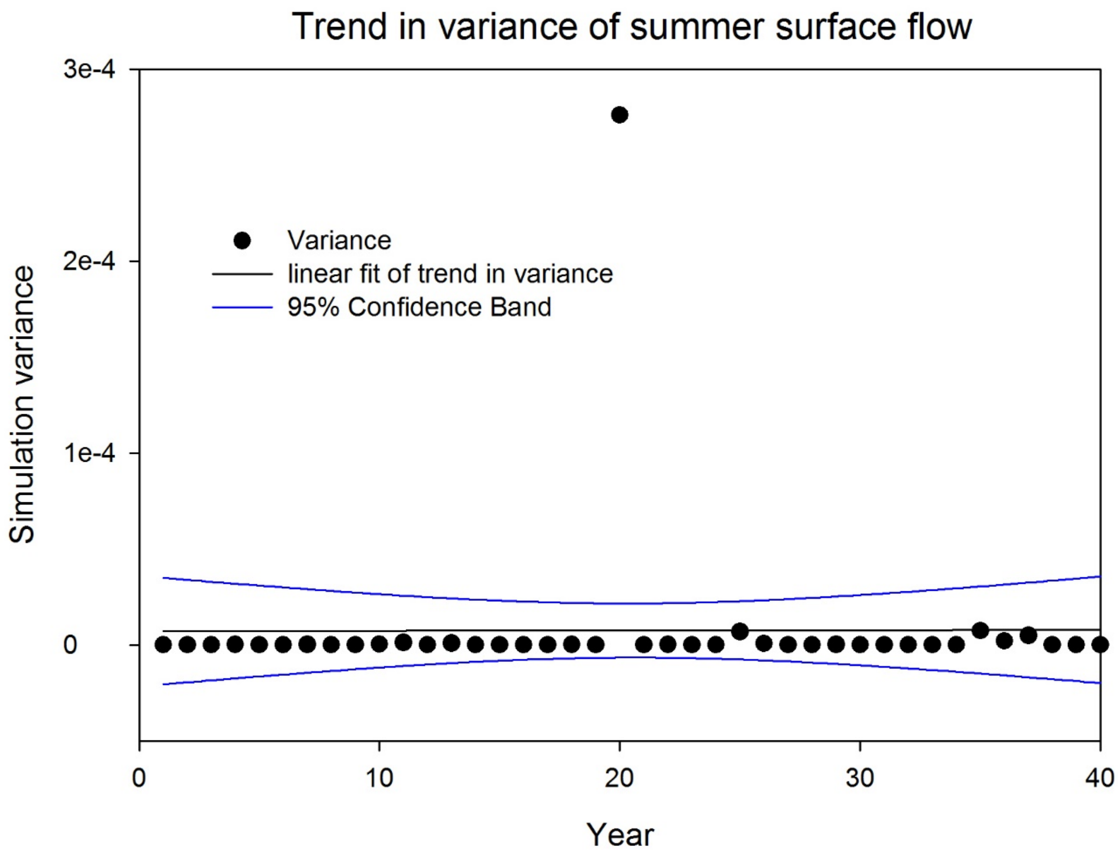


Figure 10 Simulated variance in summer surface flow. Point values represent annual variance in surface flow. Linear fit demonstrates trend in variance. Values above or below the 95% confidence interval diverge significantly from the 40-year trend.

Peak flow response to individual storms with and without fire

The analysis of fire-driven changes to runoff from a single storm event was based on 29 simulated fire events affecting >15% of watershed area with high fire severity. Four example simulation pairs that typified results for each decade of simulations demonstrate the strong positive relationship between peak flow and area burned with high severity (Figures 11-14). Simulations in the first decade did not meet the 15% high severity threshold.

During the first decade of model simulation, the average annual watershed area burned at high severity was 9%, with a range of 3-14%. We used a simulation output from year six as an example fire-runoff event, typical of the first decade of model simulations (Figure 11). The simulated landscape was

subject to a single fire that resulted in a high-severity patch comprising seven percent of the watershed area. While the stream reach passing through the high severity patch expressed a 216% increase to peak flow over the previous year unburned state, peak storm flow at the watershed outlet increased only two percent. The primary difference in pre and post-fire storm flow response at the outlet of the watershed was a change in peak flow timing, resulting in earlier and only slightly larger peak arrival (Figure 11).

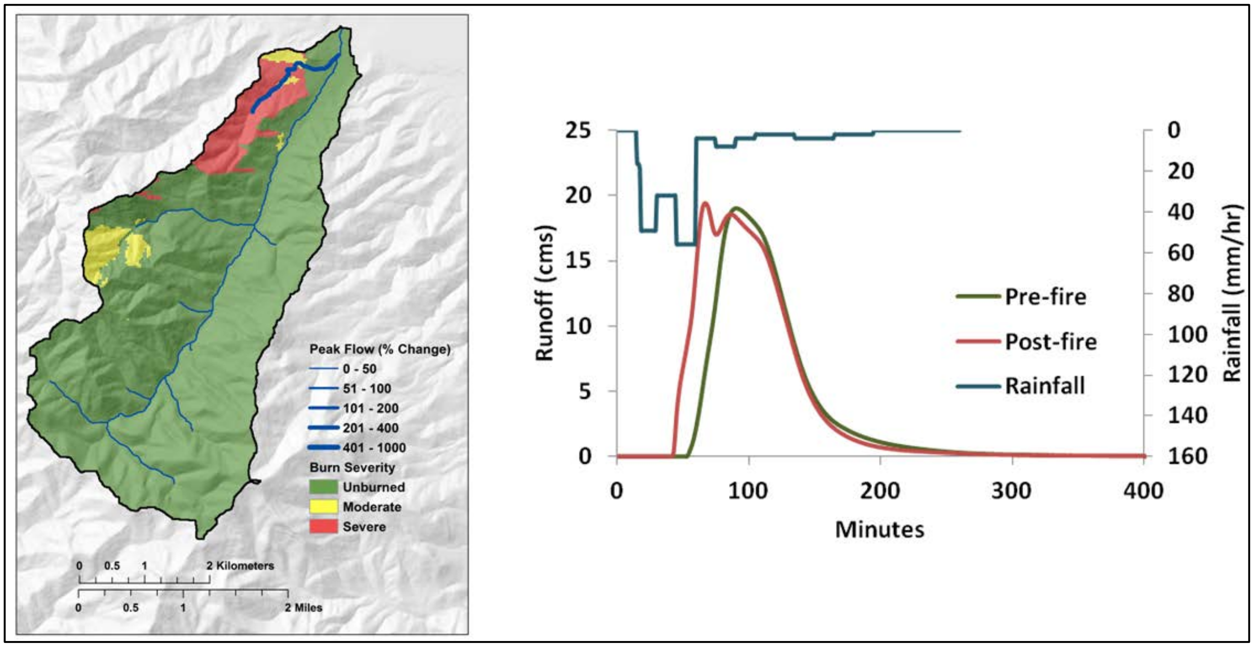


Figure 11 First decade fire simulation example. The simulated hydrograph pairs for pre and post-fire response shown here indicate that there would not be a major change to watershed behavior at the watershed outlet in response to high-severity fire affecting seven percent of the watershed. Simulated runoff is measured in cubic meters per second (cms).

Over the second decade of landscape simulations, average area burned at high severity increased to 18% (range of 7-46%), resulting in a corresponding change to peak flow following fire. In an example from year 18, both overall fire size and patch size of high-severity fire increased over the typical fire activity from the first decade of simulation (Figure 12). Approximately one fifth (19%) of the watershed burned at high severity, resulting in a 143% increase in peak flow rate at the outlet. Post-fire storm flow arrived at the watershed outlet earlier than the pre-fire flow, and expressed a more than two fold increase in peak flow rate (Figure 12).

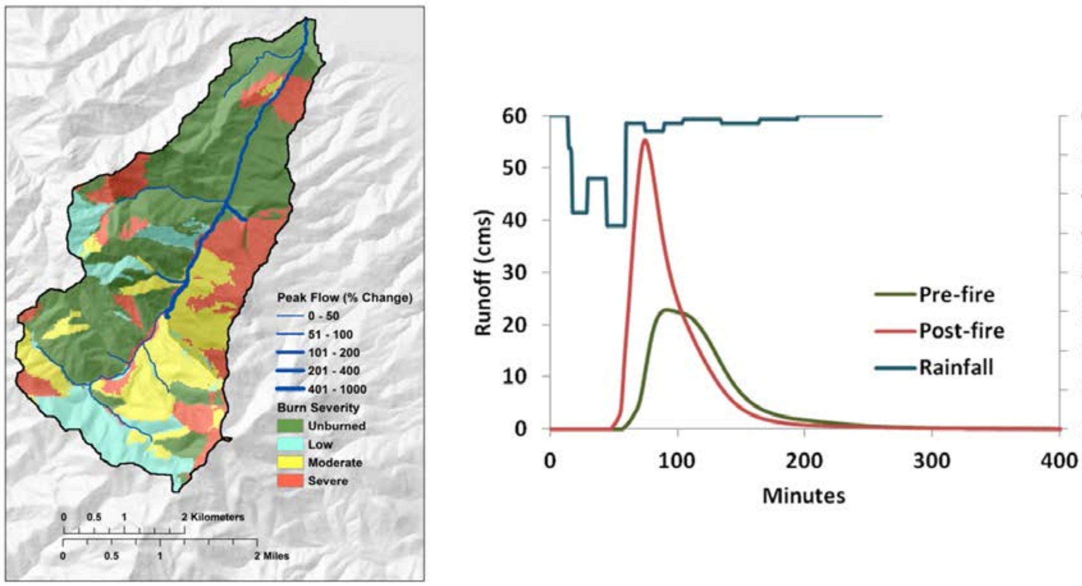


Figure 12 second decade fire simulation example. The simulated hydrograph pairs for pre and post-fire response shown here indicate that there would be a 143% change to watershed runoff at the outlet of the watershed in response to a mixed severity fire (19% high severity).

A fire during year 22 of simulations represents the third decade where mean fire severity ranged from 9% to 55% with a mean of 28%. The fire in year 22 had a mosaic of high-severity patches accounting for 37% of the total watershed area (Figure 13). The combined increase in total area burned at high-severity and the spatial concentration of high-severity fire near the watershed outlet resulted in a 188% increase in peak flow rates at the outlet of the watershed. Post-fire flows had shorter time to peak and had more 'flashy' runoff behavior than pre-fire flows (Figure 13).

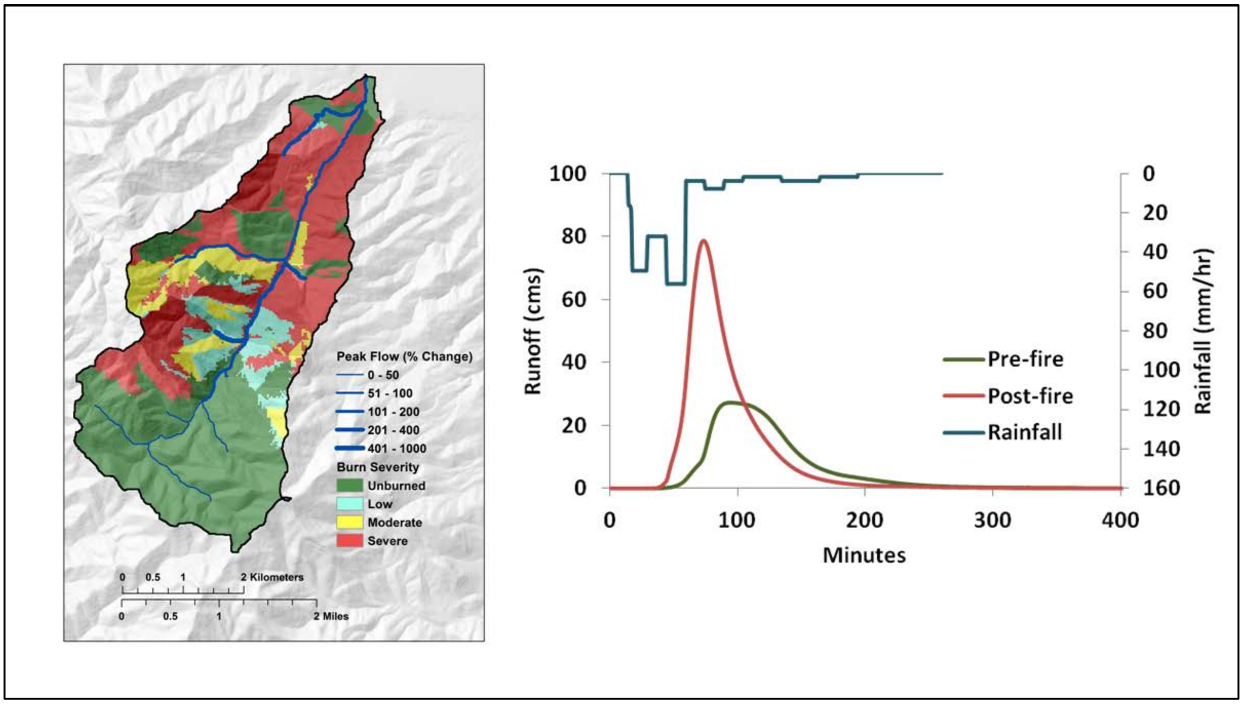


Figure 13 third decade fire simulation example. Simulated hydrograph pairs for pre and post-fire response shown here indicate that there would be a 188% change to watershed behavior at the watershed outlet in response to the 37% high-severity fire shown on the map. This fire occurred in year 22 of the simulation.

An example from the fourth decade of simulation demonstrates a "worst case scenario" fire occurring in year 33 of simulation in which 89% of the watershed area burned with high severity (Figure 14). This high-severity total represents the top of the range of high-severity burned area that averaged 32% of the watershed with a range of 6% to 89%. Under these conditions, peak flow rates increased 308% at the watershed outlet. Along with the increase in peak flow rate, time to peak flow occurred more quickly, again typifying a flashier runoff response compared to runoff events occurring earlier in the simulation period (Figure 14).

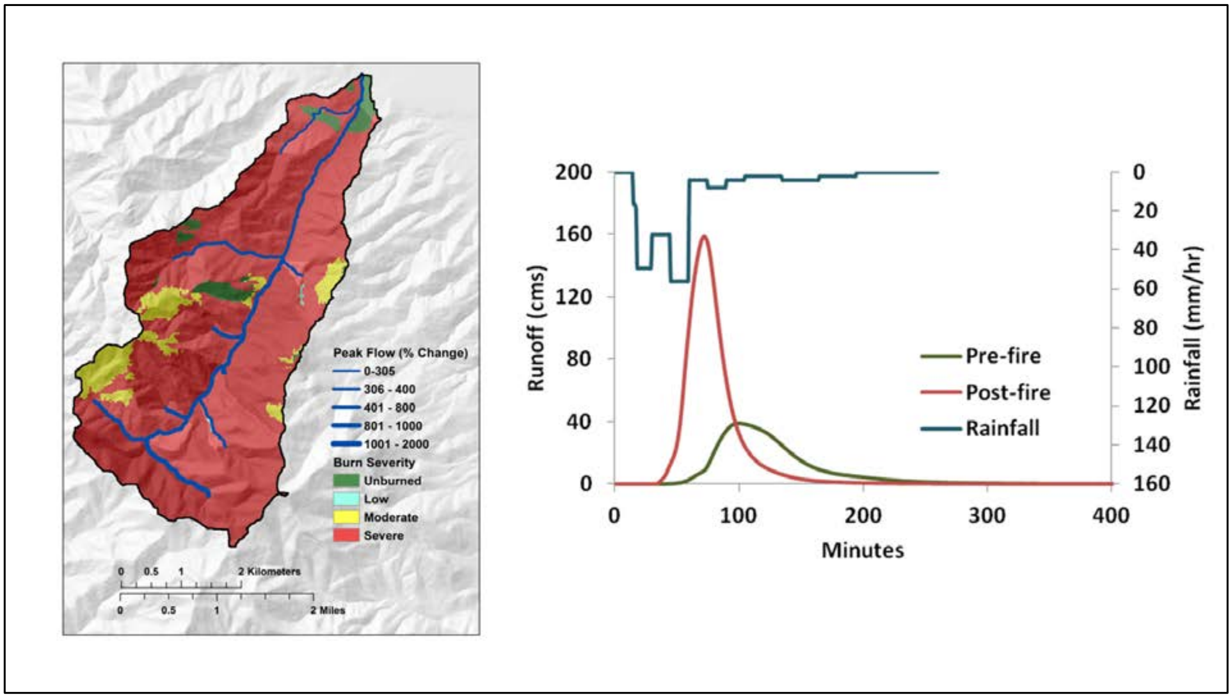


Figure 14 fourth decade fire simulation example. The simulated hydrograph pairs for pre and post-fire response shown here indicate a 308% change to watershed runoff at the watershed outlet in response to 89% of the watershed area burning at high fire severity. This fire occurred in year 33 of the simulation.

Peak flow rates increased and time to peak flow decreased with increasing patch size of high-severity fire (Figure 15). When high-severity patches were relatively small and dispersed, as in the first decade of simulation, fire effects on different contributing areas of the watershed could be distinguished from the hydrograph. Larger patches and greater total area of high severity fire resulted in a more uniform “flashy” high volume runoff over a very short time.

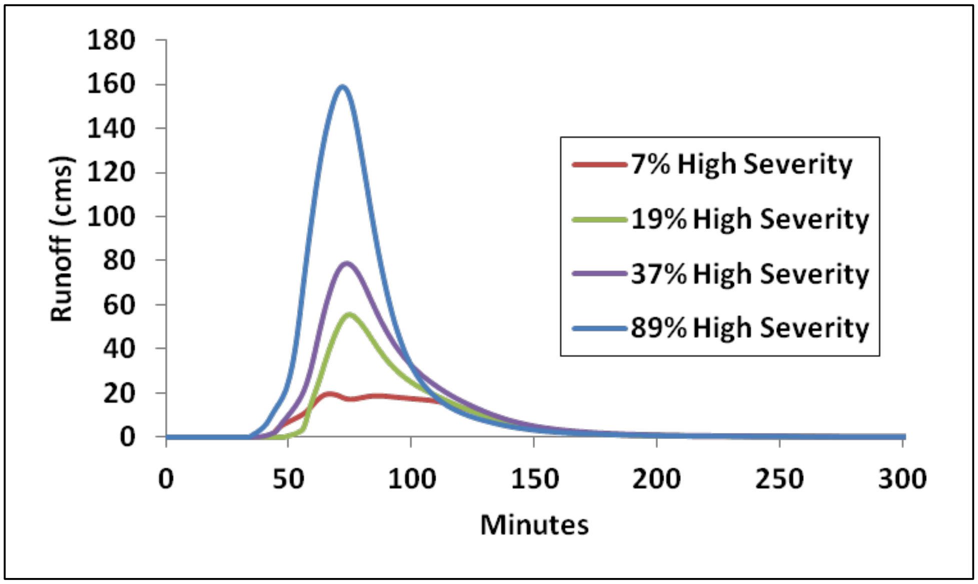


Figure 15 Comparison of hydrographs at Huachuca Canyon's outlet. This figure compares the magnitude of watershed response for the above examples (Figures 9-12) in the context of the percentage of the watershed affected by high severity fire.

Simulated post-fire peak flows exceeded the July 2014 storm response in Upper Garden Canyon in 96% of simulated fires in the Huachuca Canyon watershed (Figure 16). Equivalent storms simulated on the pre-fire landscape paired to each simulated fire did not produce runoff that was significantly different from the July 2014 storm (single factor ANOVA p-value= 0.19). The landscape example from the fourth decade of simulation (Figure 14) produced a post-fire flow approximately five times that of the July 2014 storm. Typical base flow of less than 1 cubic meter per second at the Garden Canyon station was exceeded by up to 150 fold in the highest severity fire simulations.

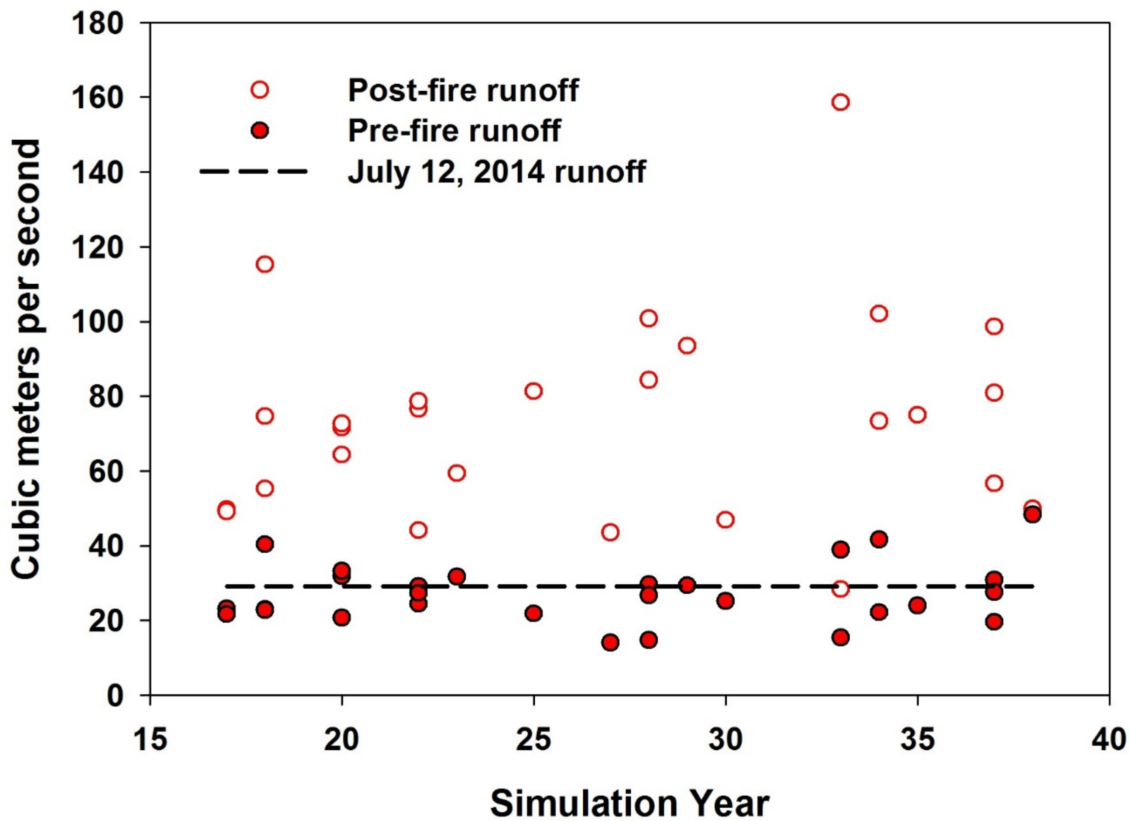


Figure 16 Simulated peak flow rates before and after fire in the Huachuca Canyon watershed. The peak flow rate on 7/12/2014 recorded in Upper Garden Canyon (black dashed line) is included for reference. Selected fires affected a minimum of 15% of the watershed area at high severity. Spatial extent of the 2014 storm is not known so simulated storm boundaries were fit to the perimeter of individual fires. Variable storm sizes provide a range of potential runoff events over the simulated period. Simulated peak flow rates prior to fire are not significantly different from the 2014 storm. After a fire, all but one simulated storm event exceeded the 2014 storm peak runoff.

Summary and Discussion

The simulation of post-fire runoff in Huachuca Canyon suggests a strong potential for fire-induced flood risk that will continue to increase for at least the next several decades. Simulated climate-induced changes to vegetation and surface cover did not significantly alter seasonal surface flow regimes during winter or summer seasons, however climate-induced changes to fire effects dramatically increased short-term peak surface flow and flood risk. Modeled winter surface flows suggest a sensitivity to the previous summer fire season and general reduction in water infiltration, coincident with the reduction in surface vegetation. While quantifying the specific runoff potential and timing of surface flow changes is beyond the scope of this work, simulated landscape changes associated with the climate projection used suggest that after a fire, future peak surface flows at the confluence of Huachuca Canyon have potential to exceed the recent extreme runoff that washed out the Garden Canyon access road by 140 to more than 300 percent depending on fire size and severity.

Implications for natural and human systems

In the pine-oak and Madrean oak woodlands of Huachuca Canyon, the patch size of high-severity, flood-associated fire events increased consistently over the simulation period. Long-term trends of increasing winter surface flow variability punctuated by more frequent winter precipitation failure are likely to push the system toward more shrub-dominated vegetation, resulting in a shift from larger trees supporting low and mixed-severity fire regimes to sprouting shrubs supporting a higher severity fire regime that reinforces the conversion toward resprouting shrubby species (Barton 1999, Barton 2002).

The downstream implications for these changes to vegetation and fire manifest at the outlet of Huachuca Canyon, where the high density of historic buildings and other sensitive infrastructure are at increased risk. Projected extreme surface flows resulting from large patches of high-severity fire, similar to those observed in Marshall Canyon in the 2011 Monument fire, suggest that culverts, bridges, roads, and buildings located near the Huachuca Creek channel would be subject to several fold greater surface flows that the roads and bridges damaged by the 2014 Garden Canyon flood event. Considering the potential for increased surface flows will be an important component of adapting to projected future climate conditions.

Model limitations and interpretation of results

Hydrologic models used in this study were not calibrated in the traditional sense. The objective of the seasonal analysis was to capture trends in surface flow generated from a projected climate change weather stream. For this reason, results are interpreted as trends in mean flow and not as quantified changes to surface flow volume. The objective of the single storm event analysis was to capture changes in flow attributable to a single fire-rainstorm pairing. For this analysis, calibration was designed to capture peak flow volume but not total flow, because peak flows are of greatest concern for flood-related damage. Inherent model limitations also limited our ability to perform a comprehensive calibration.

The SWAT model was used to investigate seasonal trends in runoff behavior because it works at a daily time step, making it appropriate for the daily weather streams used by FireBGCv2 and also flexible enough to accommodate annual landscape trends produced by the FireBGCv2 vegetation and fire simulations. An important consideration for this region, where a considerable amount of flooding concern is related to monsoonal flash floods, is that daily time steps of the SWAT model cannot properly account for anticipated short-duration high-intensity storms of concern. For this reason we used SWAT to track longer-term trends in seasonal surface flow resulting from accumulated landscape changes over the simulation period.

KINEROS2 has different advantages and limitations. This model is appropriate for small catchments and has been extensively tested on basins up to ~100 km^2. This event-based model is limited to sub-daily time steps so it is appropriate for capturing monsoonal type events that are of greatest concern following a fire. Although K2 is expected to perform well when modeling post-fire runoff generation (infiltration excess), it is not designed to capture the more subtle processes involved with pre-fire runoff generation from forested areas (saturation excess).

Given the series of model limitations, calibration challenges, and the nature of this study that uses simulated weather events and simulated landscapes, the most appropriate way to interpret model results is to look at magnitude of flow change and variance between simulations. By recognizing that quantitative results are an unrealistic outcome from this study and focusing on a more qualitative assessment of results, we feel that this study provides valuable information for decision making.

For the SWAT model, results were presented as deviations from the 40-year mean of winter and summer 'wet' seasons. The presentation of Z-scores and variances demonstrate anticipated trends in runoff without the need to model quantitative runoff explicitly. K2 simulations demonstrate the relative relationships between changing climate, anticipated fire severity, and differences between pre-fire and post-fire storm runoff. Differences in peak flow rates and their relation to the proportion of the watershed affected by high-severity fire, expressed as degree of change, again provides useful information without attempting to simulate explicit flow rates.

Conclusion

Climate-change induced changes to fire and flood risk at Fort Huachuca are consistent with projected risks faced by landscape managers across the American Southwest. Changes to temperature and precipitation regimes are likely to result in major shifts in vegetation and surface cover, resulting in new disturbance regimes, new risks, and new challenges for both humans and ecosystems. Landscapes managed by multiple agencies and public and private owners will have a unique set of challenges reconciling diverse and sometimes conflicting land management goals. Risk transmission from one ownership to another (Ager et al. 2014, Haas et al. 2015) will continue to be an issue and can be leveraged as a vehicle for bringing together a range of stakeholders to develop memoranda of understanding for resource sharing and co-management of risk (Olson and Bengston 2015). As landscape change accelerates, it will be important to promote the "all in this together" understanding of landscape management to develop cohesive, long-term management coordination.

References

Abatzoglou, J. T. 2013. Development of gridded surface meteorological data for ecological applications and modelling. International Journal of Climatology 33:121-131.

Ager, A. A., M. A. Day, M. A. Finney, K. Vance-Borland, and N. M. Vaillant. 2014. Analyzing the transmission of wildfire exposure on a fire-prone landscape in Oregon, USA. Forest Ecology and Management 334:377-390.

Allen, C. D., D. D. Breshears, and N. G. McDowell. 2015. On underestimation of global vulnerability to tree mortality and forest die-off from hotter drought in the Anthropocene. Ecosphere 6:129:55.

Barton, A. M. 2002. Intense wildfire in southeastern Arizona: transformation of a Madrean oak-pine forest to oak woodland. Forest Ecology and Management 165:205-212.

Barton, A. M. 1999. Pines versus oaks: effects of fire on the composition of Madrean forests in Arizona. Forest Ecology and Management 120:143-156.

Cawson, J., G. Sheridan, H. Smith, and P. Lane. 2012. Surface runoff and erosion after prescribed burning and the effect of different fire regimes in forests and shrublands: a review. International Journal of Wildland Fire 21:857-872.

Crimmins, M. A. 2011. Interannual to decadal changes in extreme fire weather event frequencies across the southwestern United States. International Journal of Climatology 31:1573-1583.

DeBano, L.F., Ffolliott, P. F. and Baker Jr, M. B. 1996. Fire severity effects on water resources. Pages 77. in: Ffolliot, P. F., L. F. Debano, M. B. Baker, et al, editors. Symposium on Effects of Fire on Madrean Province Ecosystems. March 1996. US Dept. of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. .

DeBano, L. F., D. G. Neary, and P. F. Ffolliott. 1998. Fire effects on ecosystems. John Wiley & Sons, New York.

Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy. 2013. Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment. Island Press, May 2, 2013Washington, DC. 531 p.

Grimm, N. B., M. D. Staudinger, A. Staudt, S. L. Carter, F. S. Chapin III, P. Kareiva, M. Ruckelshaus, and B. A. Stein. 2013. Climate-change impacts on ecological systems: introduction to a US assessment. Frontiers in Ecology and the Environment 11:456-464.

Haas, J. R., D. E. Calkin, and M. P. Thompson. 2015. Wildfire risk transmission in the Colorado Front Range, USA. Risk Analysis 35:226-240.

Lyon, R. 2013. Using rainfall-runnoff models to characterize the flow regime of desert streams in the U.S. southwest. MS Thesis. University of Arizona. 89 p.

Maurer, E. P., H. G. Hidalgo, T. Das, M. Dettinger, and D. Cayan. 2010. The utility of daily large-scale climate data in the assessment of climate change impacts on daily streamflow in California. Hydrology and Earth System Sciences 14:1125-1138.

McDowell, N. G., C. D. Allen. 2015. Darcy's law predicts widespread forest mortality under climate warming. Nature Climate Change 5:669-672.

Miller, J. D., J. W. Nyhan, and S. R. Yool. 2003. Modeling potential erosion due to the Cerro Grande Fire with a GIS-based implementation of the Revised Universal Soil Loss Equation. International Journal of Wildland Fire 12:85-100.

Miller, J. D., A. E. Thode. 2007. Quantifying burn severity in a heterogeneous landscape with a relative version of the delta Normalized Burn Ratio (dNBR). Remote Sensing of Environment 109:66-80.

Miller, M. E., L. H. MacDonald, P. R. Robichaud, and W. J. Elliot. 2012. Predicting post-fire hillslope erosion in forest lands of the western United States. International Journal of Wildland Fire 20:982-999.

Moody, J. A., R. A. Shakesby, P. R. Robichaud, S. H. Cannon, and D. A. Martin. 2013. Current research issues related to post-wildfire runoff and erosion processes. Earth-Science Reviews 122:10-37.

Natural Resources Conservation Service, USDA. 2012. Web Soil Survey. Accessed: October 1, 2012. http://websoilsurvey.nrcs.usda.gov/.

O'Connor, C. D., D. A. Falk, A. M. Lynch, and T. W. Swetnam. 2014. Fire severity, size, and climate associations diverge from historical precedent along an ecological gradient in the Pinaleño Mountains, Arizona, U.S.A. Forest Ecology and Management 329:264-278.

Olson, R. L., D. N. Bengston. 2015. A world on fire. GTR-NS-152. U.S. Forest Service Northern Research Station. Newtown Square, PA. 52 p.

Robichaud, P. R., J. L. Beyers, and D. G. Neary. 2000. Evaluating the effectiveness of postfire rehabilitation treatments RMRS GTR-63. U.S. Forest Service Rocky Mountain Research Station. Fort Collins, CO. 89 p.

Sheffield, J., A. P. Barrett, B. Colle, D. Nelun Fernando, R. Fu, K. L. Geil, Q. Hu, J. Kinter, S. Kumar, and B. Langenbrunner. 2013. North American Climate in CMIP5 Experiments. Part I: Evaluation of Historical Simulations of Continental and Regional Climatology*. Journal of Climate 26:9209-9245.

Sheppard, P. R., A. C. Comrie, G. D. Packin, K. Angersbach, and M. K. Hughes. 1999. The climate of the Southwest: CLIMAS Report Series CL 1-99. Institute for the Study of Planet Earth, University of Arizona.

Swetnam, T.W. and Baisan, C. H. 1996. Fire histories of montane forests in the Madrean Borderlands. 15 Pages. in: Ffolliott, P. F., L. F. DeBano, M. B. Baker, et al, editors. Effects of fire on Madrean Province ecosystems: a symposium proceedings. General Technical Report RM-GTR-289. December 1996. USDA Forest Service Rocky Mountain Forest and Range Experiment Station. Fort Collins, CO.

Turner, M. G., W. H. Romme, and R. H. Gardner. 1999. Prefire heterogeneity, fire severity, and early postfire plant reestablishment in subalpine forests of Yellowstone National Park, Wyoming. International Journal of Wildland Fire 9:21-36.

Westerling, A., A. Gershunov, T. Brown, D. Cayan, and M. Dettinger. 2003. Climate and wildfire in the western United States. Bulletin of the American Meteorological Society 84:595-604.

Youberg, A. and P. Pearthree. 2011. Post-Monument Fire floods and debris flows in the Huachuca Mountains, southern Arizona. Jan 5, 2015, 2015. http://azgeology.azgs.az.gov/article/environmental-geology/2011/09/post-monument-fire-floods-and-debris-flows-huachuca-mountains.

Appendix A

Table 1 Look Up Table associating landscape properties to hydrologic parameters. This table relates the look up code (CLASS) to the soil group (ABCD) and associated Curve Number (CN), the percent canopy cover (%CC), intercepted rainfall depth (INT), Manning's n (N), and percent impervious (IMPERV). The NAME category provides the dominant species for a given area and the associated basal area or the degree of burn severity.

CLASS	NAME	A	B	C	D	%CC	INT	N	IMPERV
101	Mesquite 60_100 m2/ha	54	54	73	78	51	1.179	0.615	0
102	Juniper 60_100 m2/ha	54	54	73	78	50	1.179	0.615	0
103	Pinyon Pine 60_100 m2/ha	54	54	73	78	50	1.179	0.615	0
104	Manzanita (Shrub) 60_100 m2/ha	61	75	83	86	25	1.179	0.056	0
105	Evergreen Oak Complex 60_100 m2/ha	54	54	73	78	50	1.179	0.615	0
106	Broadleaf Riparian 60_100 m2/ha	54	54	73	78	50	1.179	0.615	0
107	Arizona Ash 60_100 m2/ha	54	54	73	78	50	1.179	0.615	0
108	Decid. Montane Oak Comp. 60_100 m2/ha	54	54	73	78	50	1.179	0.615	0
109	Chihuahua Pine (PILE) 60_100 m2/ha	54	54	68	75	50	1.179	0.82	0
110	Apache Pine 60_100 m2/ha	54	54	68	75	50	1.179	0.82	0
111	Ponderosa/AZ Pine 60_100 m2/ha	54	54	68	75	50	1.179	0.82	0
112	White Fir 60_100 m2/ha	54	54	68	75	50	1.179	0.82	0
113	Douglas Fir 60_100 m2/ha	54	54	68	75	50	1.179	0.82	0
114	Southwestern White Pine 60_100 m2/ha	54	54	68	75	50	1.179	0.82	0
115	Quaking Aspen 60_100 m2/ha	54	54	73	78	50	1.179	0.615	0
116	Mixed Grasses 60_100 m2/ha	48	69	78	83	43	1.179	0.204	0
117	Mixed Grasses 60_100 m2/ha	48	69	78	83	43	1.179	0.204	0
201	Mesquite 45_60 m2/ha	55	55	75	80	50	1.15	0.6	0
202	Juniper 45_60 m2/ha	55	55	75	80	50	1.15	0.6	0
203	Pinyon Pine 45_60 m2/ha	55	55	75	80	50	1.15	0.6	0
204	Manzanita (Shrub) 45_60 m2/ha	63	77	85	88	25	1.15	0.055	0
205	Evergreen Oak Complex 45_60 m2/ha	55	55	75	80	50	1.15	0.6	0
206	Broadleaf Riparian 45_60 m2/ha	55	55	75	80	50	1.15	0.6	0
207	Arizona Ash 45_60 m2/ha	55	55	75	80	50	1.15	0.6	0
208	Decid. Montane Oak Comp. 45_60 m2/ha	55	55	75	80	50	1.15	0.6	0
209	Chihuahua Pine (PILE) 45_60 m2/ha	55	55	70	77	50	1.15	0.8	0
210	Apache Pine 45_60 m2/ha	55	55	70	77	50	1.15	0.8	0
211	Ponderosa/AZ Pine 45_60 m2/ha	55	55	70	77	50	1.15	0.8	0
212	White Fir ba 45_60 m2/ha	55	55	70	77	50	1.15	0.8	0
213	Douglas-Fir ba 45_60 m2/ha	55	55	70	77	50	1.15	0.8	0
214	Southwestern White Pine 45_60 m2/ha	55	55	70	77	50	1.15	0.8	0
215	Quaking Aspen 45_60 m2/ha	55	55	75	80	50	1.15	0.6	0
216	Mixed Grasses 45_60 m2/ha	49	71	80	85	43	1.15	0.199	0

CLASS	NAME	A	B	C	D	%CC	INT	N	IMPERV
217	Mixed Grasses 45_60 m2/ha	49	71	80	85	43	1.15	0.199	0
301	Mesquite 30_45 m2/ha	56	56	77	82	49	1.121	0.585	0
302	Juniper 30_45 m2/ha	56	56	77	82	49	1.121	0.585	0
303	Pinyon Pine 30_45 m2/ha	56	56	77	82	49	1.121	0.585	0
304	Manzanita (Shrub) 30_45 m2/ha	65	79	87	90	24	1.121	0.054	0
305	Evergreen Oak Complex 30_45 m2/ha	56	56	77	82	49	1.121	0.585	0
306	Broadleaf Riparian 30_45 m2/ha	56	56	77	82	49	1.121	0.585	0
307	Arizona Ash 30_45 m2/ha	56	56	77	82	49	1.121	0.585	0
308	Decid. Montane Oak Comp. 30_45 m2/ha	56	56	77	82	49	1.121	0.585	0
309	Chihuahua Pine (PILE) 30_45 m2/ha	56	56	72	79	49	1.121	0.78	0
310	Apache Pine 30_45 m2/ha	56	56	72	79	49	1.121	0.78	0
311	Ponderosa/Azpine 30_45 m2/ha	56	56	72	79	49	1.121	0.78	0
312	White Fir 30_45 m2/ha	56	56	72	79	49	1.121	0.78	0
313	Douglas Fir 30_45 m2/ha	56	56	72	79	49	1.121	0.78	0
314	Southwestern White Pine 30_45 m2/ha	56	56	72	79	49	1.121	0.78	0
315	Quaking Aspen 30_45 m2/ha	56	56	77	82	49	1.121	0.585	0
316	Mixed grasses 30_45 m2/ha	49	71	80	85	43	1.15	0.199	0
317	Mixed grasses 30_45 m2/ha	49	71	80	85	43	1.15	0.199	0
401	Mesquite 15_30 m2/ha	58	58	79	84	48	1.093	0.57	0
402	Juniper 15_30 m2/ha	58	58	79	84	48	1.093	0.57	0
403	Pinyon Pine 15_30 m2/ha	58	58	79	84	48	1.093	0.57	0
404	Manzanita (Shrub) 15_30 m2/ha	66	81	89	92	24	1.093	0.052	0
405	Evergreen Oak Complex 15_30 m2/ha	58	58	79	84	48	1.093	0.57	0
406	Broadleaf Riparian 15_30 m2/ha	58	58	79	84	48	1.093	0.57	0
407	Arizona Ash 15_30 m2/ha	58	58	79	84	48	1.093	0.57	0
408	Decid. Montane Oak Comp. 15_30 m2/ha	58	58	79	84	48	1.093	0.57	0
409	Chihuahua Pine (PILE) 15_30 m2/ha	58	58	74	81	48	1.093	0.761	0
410	Apache Pine 15_30 m2/ha	58	58	74	81	48	1.093	0.761	0
411	Ponderosa/Az Pine 15_30 m2/ha	58	58	74	81	48	1.093	0.761	0
412	White Fir 15_30 m2/ha	58	58	74	81	48	1.093	0.761	0
413	Douglas Fir 15_30 m2/ha	58	58	74	81	48	1.093	0.761	0
414	Southwestern White Pine 15_30 m2/ha	58	58	74	81	48	1.093	0.761	0
415	Quaking Aspen 15_30 m2/ha	58	58	79	84	48	1.093	0.57	0
416	Mixed Grasses 15_30 m2/ha	49	71	80	85	43	1.15	0.199	0
417	Mixed Grasses 15_30 m2/ha	49	71	80	85	43	1.15	0.199	0
501	Mesquite 0_15 m2/ha	59	59	81	86	46	1.066	0.556	0
502	Juniper 0_15 m2/ha	59	59	81	86	46	1.066	0.556	0
503	Pinyon Pine 0_15 m2/ha	59	59	81	86	46	1.066	0.556	0
504	Manzanita (Shrub) 0_15 m2/ha	68	83	92	95	23	1.066	0.051	0
505	Evergreen Oak Complex 0_15 m2/ha	59	59	81	86	46	1.066	0.556	0

CLASS	NAME	A	B	C	D	%CC	INT	N	IMPERV
506	Broadleaf Riparian 0_15 m2/ha	59	59	81	86	46	1.066	0.556	0
507	Arizona Ash 0_15 m2/ha	59	59	81	86	46	1.066	0.556	0
508	Decid. Montane Oak Comp. 0_15 m2/ha	59	59	81	86	46	1.066	0.556	0
509	Chihuahua Pine (PILE) 0_15 m2/ha	59	59	75	83	46	1.066	0.741	0
510	Apache Pine 0_15 m2/ha	59	59	75	83	46	1.066	0.741	0
511	Ponderosa/AZ Pine 0_15 m2/ha	59	59	75	83	46	1.066	0.741	0
512	White Fir 0_15 m2/ha	59	59	75	83	46	1.066	0.741	0
513	Douglas Fir 0_15 m2/ha	59	59	75	83	46	1.066	0.741	0
514	Southwestern White Pine 0_15 m2/ha	59	59	75	83	46	1.066	0.741	0
515	Quaking Aspen 0_15 m2/ha	59	59	81	86	46	1.066	0.556	0
516	Mixed Grasses 0_15 m2/ha	49	71	80	85	43	1.15	0.199	0
517	Mixed Grasses 0_15 m2/ha	49	71	80	85	43	1.15	0.199	0
601	Mesquite_Low	59	60	78	82	43	1.121	0.01	0
602	Juniper_Low	59	60	78	82	43	1.121	0.01	0
603	Pinyon Pine_Low	59	60	78	82	43	1.121	0.01	0
604	Manzanita (Shrub)_Low	65	79	86	89	21	1.121	0.01	0
605	Evergreen Oak Complex_Low	59	60	78	82	43	1.121	0.01	0
606	Broadleaf Riparian_Low	59	60	78	82	43	1.121	0.01	0
607	Arizona Ash_Low	59	60	78	82	43	1.121	0.01	0
608	Decid Montane Oak Comp_Low	59	60	78	82	43	1.121	0.01	0
609	Chihuahua Pine (PILE)_Low	49	71	80	85	43	1.121	0.199	0
610	Apache Pine_Low	49	71	80	85	43	1.121	0.199	0
611	Ponderosa/AZ Pine_Low	49	71	80	85	43	1.121	0.199	0
612	White Fir_Low	49	71	80	85	43	1.121	0.199	0
613	Douglas Fir_Low	49	71	80	85	43	1.121	0.199	0
614	Southwestern White Pine_Low	49	71	80	85	43	1.121	0.199	0
615	Quaking Aspen_Low	59	60	78	82	43	1.121	0.199	0
616	Mixed grasses_Low	49	71	80	85	43	1.15	0.199	0
617	Mixed grasses_Low	49	71	80	85	43	1.15	0.199	0
701	Mesquite_Moderate	65	65	80	85	34	1.093	0.005	0
702	Juniper _Moderate	65	65	80	85	34	1.093	0.005	0
703	Pinyon Pine_Moderate	65	65	80	85	34	1.093	0.005	0
704	Manzanita (Shrub)_Moderate	68	82	88	90	17	1.093	0.005	0
705	Evergreen Oak Complex_Moderate	65	65	80	85	34	1.093	0.058	0
706	Broadleaf Riparian_Moderate	65	65	80	85	34	1.093	0.058	0
707	Arizona Ash_Moderate	65	65	80	85	34	1.093	0.058	0
708	Decid. Montane Oak Comp._Moderate	65	65	80	85	34	1.093	0.058	0
709	Chihuahua Pine (PILE)_Moderate	55	76	82	88	34	1.093	0.058	0
710	Apache Pine_Moderate	55	76	82	88	34	1.093	0.058	0
711	Ponderosa/AZ Pine_Moderate	55	76	82	88	34	1.093	0.058	0

CLASS	NAME	A	B	C	D	%CC	INT	N	IMPERV
712	White Fir_Moderate	55	76	82	88	34	1.093	0.058	0
713	Douglas-Fir_M	55	76	82	88	34	1.093	0.058	0
714	Southwestern White Pine_Moderate	55	76	82	88	34	1.093	0.058	0
715	Quaking Aspen_Moderate	65	65	80	85	34	1.093	0.058	0
716	Mixed grasses_Moderate	49	71	80	85	43	1.15	0.05	0
717	Mixed grasses_Moderate	49	71	80	85	43	1.15	0.05	0
801	Mesquite_Severe	70	71	83	94	25	1.066	0.003	0
802	Juniper_Severe	70	71	83	94	25	1.066	0.003	0
803	Pinyon Pine_Severe	70	71	83	94	25	1.066	0.003	0
804	Manzanita (Shrub)_Severe	73	88	91	94	12	1.066	0.003	0
805	Evergreen Oak Complex_Severe	70	71	83	94	25	1.066	0.017	0
806	Broadleaf Riparian_Severe	70	71	83	94	25	1.066	0.017	0
807	Arizona Ash_Severe	70	71	83	94	25	1.066	0.017	0
808	Decid. Montane Oak Comp._Severe	70	71	83	94	25	1.066	0.017	0
809	Chihuahua Pine (PILE)_Severe	60	82	85	94	25	1.066	0.017	0
810	Apache Pine_Severe	60	82	85	94	25	1.066	0.017	0
811	Ponderosa/AZ Pine_Severe	60	82	85	94	25	1.066	0.017	0
812	White Fir_Severe	60	82	85	94	25	1.066	0.017	0
813	Douglas Fir_Severe	60	82	85	94	25	1.066	0.017	0
814	Southwestern White Pine_Severe	60	82	85	94	25	1.066	0.017	0
815	QuakingAspen_Severe	70	71	83	94	25	1.066	0.017	0
816	Mixed grasses_Severe	49	71	80	94	43	1.15	0.03	0
817	Mixed grasses_Severe	49	71	80	94	43	1.15	0.03	0

Table 2 recorded rainfall in Garden Canyon. This table shows the portion of recorded rainfall on 7/12/2014 that was used to create the hyetograph for K2 simulations.

Time	**Rainfall (in)**
19:15	0.12
19:30	0.30
19:45	0.34
20:00	0.52
20:15	0.07
20:30	0.06
20:45	0.04
21:00	0.02
21:15	0.02
21:30	0.06
21:45	0.02
22:00	0.02
22:15	0.02

Appendix B – Spatial Analysis Details

Several steps were taken to manipulate the ascii outputs from FireBGCv2 to make landscape inputs for the AGWA parameter estimating scheme. This involved the development of an iterated value change function in ArcGIS model builder as well as the use of a program called Bulk Rename Utility to change the names of the FireBGCv2 outputs for compatibility with the model builder. The ArcGIS model builder iterated raster preparation for the several hundred landscapes that were created by FireBGCv2.

The sppIDbar (dominant species by basal area), the basarea (basal area (m2/ha)), and treemort (tree mortality (%)) ascii outputs from FireBGCv2 were transformed to ArcGIS grids projected into NAD 83 zone 12 format. Additionally the basarea (m2) output was reclassified into five categories (0-15, 15-30, 30-45, 45-60, 60-100) (m2/ha). The sppIDbar was combined with the basarea grids to account for basal area loss over the course of the landscape simulations. This combination of landcover type and basal area category was used as the unburned condition, and is correlated to hydrologic parameters via the landscape look up table in Appendix A.

Burn severity grids for the landscape were generated using tree mortality outputs from FireBGCv2. This was done by considering areas that were 0-10% dead as unburned, 10-30% dead as low burn severity, 30-70% dead as moderately burned, and 70-100% dead as severely burned. Once the tree mortality grid was reclassified in this way, landscapes with greater than 15% high severity were considered for analysis.

Appendix F: Naval Base Coronado Drought, Temperature and Fire Technical Report 2016

O'Connor, C., Treanor, F., Falk, D., and G. Garfin. (2016) SERDP RC-2232 Interim Report 3: Climate change-type drought, temperature, and fire effects on Naval Base Coronado inland training sites, San Diego County, California. Technical Report to Naval Base Coronado, US Department of the Navy. 29 pp.Issued: June 2016.

SERDP RC-2232 Interim Report 3: Climate change-type drought, temperature, and fire effects on Naval Base Coronado inland training sites, San Diego County, California

October 16, 2016

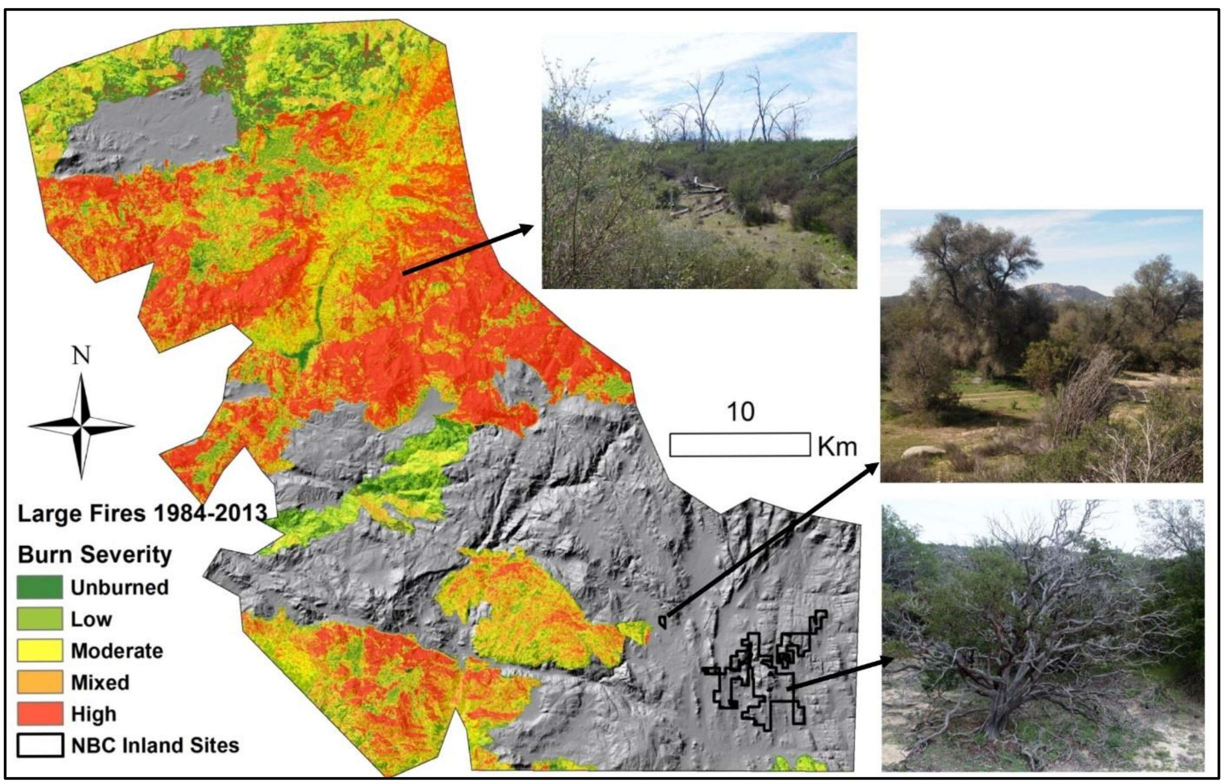
Principal Investigator* Gregg G. Garfin, School of Natural Resources and the Environment
Principal Investigator: Raphael Sagarin, Biosphere 2 Ocean

University of Arizona

Report prepared by:
Christopher D. O'Connor, School of Natural Resources and the Environment
Forrest Treanor, School of Natural Resources and the Environment
Donald A. Falk, School of Natural Resources and the Environment
Gregg G. Garfin, School of Natural Resources and the Environment

In collaboration with:
Jonathan Overpeck, Institute of the Environment
Anna Haworth, Acclimatise
Jeremy Weiss, Institute of the Environment
John Firth, Acclimatise
Alastair Baglee, Acclimatise

*New Principal Investigator following the death of Dr. Sagarin



Executive Summary

The specialized training facilities at Camp Michael Monsoor, Camp Morena, and Remote Training Site Warner Springs are examples of a network of critical infrastructure for the Department of Defense Mission to protect the safety of United States citizens and strategic interests of the U.S. Government around the globe. These facilities are embedded in natural landscapes at remote locations where the natural vegetation, topography, and daily weather extremes are as much a part of the training infrastructure as the built environment. Camp Michael Monsoor and Camp Morena are embedded within the Southern California Chaparral Ecosystem, in a landscape that provides unique training opportunities that simulate conditions in active military theaters far from the United States, but that brings with it unique challenges of extreme fire behavior, sensitivity to human land uses, vulnerability to introduced species, and unknown sensitivities to rapidly changing climate conditions. Reliance on these installations for critical training over the coming decades suggests that a greater understanding of the long-term impacts of changing climate, fire, and human impacts within and around the training sites will be necessary to make informed management decisions that promote sustainability of training operations and of the greater chaparral ecosystem.

Approximately 90% of the vegetation at Camp Michael Monsoor and Camp Morena is classified as dry-mesic (low shrub) chaparral or mesic (shrub with sparse tree overstory) chaparral. Both systems are highly fire adapted and fire dependent to maintain species composition, structure, and minimize encroachment by introduced invasive grasses. Exclusion of fire from southern California dry-mesic chaparral (DMC) for more than 70 years reduced tolerance to drought and temperature extremes and is likely to accelerate the loss of total vegetative cover. Fires affecting parts of these “old growth” dry chaparral systems over the past two decades demonstrate their resilience; were even after high-severity (stand-replacing) fire, chaparral regeneration (expressed as a return to pre-fire vegetation spectral signature) occurred within two years under moist winter conditions and four to six years under average moisture conditions. Mesic chaparral (MC) in surrounding ecosystems was generally less sensitive to climate extremes than old growth DMC, expressing no difference in climate sensitivity between younger and older MC stands. MC expressed greater sensitivity to high-severity fire, often requiring ten years or more to regenerate following high-severity fire.

Other vegetation types were less wide spread throughout NBC inland training sites and included varying degrees of sensitivity to climate extremes and high-severity fire. In a series of environmental factors tested against plant drought stress, increasing temperature was the strongest predictor of plant

stress, surpassing drought and Santa Ana wind conditions. Results suggest that the “old growth” chaparral systems that are most prevalent on NBC inland training sites are the least tolerant to increasing temperatures and drought prevalence but that reintroducing fire has potential to restore some level of resilience to changing climate conditions. Fires in MC systems are also likely to improve long-term adaptability to future climate conditions and to reduce the potential for invasion by introduced grasses, however post-fire recovery in these tree-dominated systems is expected to take more time than in dry-mesic shrublands.

Introduction

The United States Department of Defense has a footprint that touches all regions of the globe, exposing its personnel, infrastructure, and mission to a range of environmental and social conditions that are expected to worsen as a result of rapidly changing climate conditions over the next century. In response to this new reality, executive orders 13514 and 13653 instruct all agencies of the United States Government to evaluate climate change risks and to manage these risks to promote the long term sustainability of agency missions (DoD 2014). Within in the United States, The Department of Defense operates training facilities on approximately 19 million acres (7.7 million hectares), making it the 5th largest land managing agency in the United States (Gorte et al. 2012). All federal lands are subject to environmental regulations designed to promote sustainability of managed and natural systems, with specific reference to maintenance of ecological function. As part of this mandate, emphasis is placed on protection of soil and water resources, as well as designing specific management activities to meet the needs of sensitive or threatened plant and animal species. For more than 30 years, training and operations planning and execution have incorporated environmental regulatory compliance, including a series of ecological monitoring programs developed independently among different branches of the armed services. The future of this balance between training, operations, and environmental commitments is uncertain under rapidly changing environmental conditions.

Climate change effects on the Pacific Southwest

Over the next several decades, the southwestern United States is expected to experience a trend of warming annual mean temperatures and increasing variability in seasonal precipitation (Garfin et al. 2014). Global Climate Model (GCM) projections for the southwest region forecast a 1-4 $^{\circ}$F (0.5-2.2 $^{\circ}$C) increase in mean summer and fall temperatures by the year 2050, with an increasing rate of warming nearer the end of the 21st century (Garfin et al. 2013). While changes to precipitation patterns are less certain, an increase in short-duration, high intensity winter storms and potential reduction in

total winter precipitation, concurrent with a reduced number of frost-free days, suggests that late winter snowpack is likely to decline and winter-season flooding is likely to increase. The suite of available GCM projections suggest that the region along the US-Mexico Border is likely to experience the most severe temperature increases and reductions in winter precipitation in the southwest region. Rapid changes to regional climate are likely to affect vegetation and water supplies, and when coupled with increasing urban encroachment, are expected to result in more frequent and larger wildfires.

From 2012-2014 California experienced the most severe drought conditions in more than 1200 years (Griffin and Anchukaitis 2014). Drought conditions have persisted through the summer of 2015 and coincide with record high temperatures (Vose et al. 2014). Over the past 15 years, average annual temperatures in the southern interior of California have increased half a degree Celsius and maximum summer temperatures have increased almost two degrees Celsius (PRISM 2013). This period of increasing temperature extremes also coincides with four of the five largest and most damaging fires in California history (CalFire 2015). These trends of increasing extreme temperatures coinciding with extreme drought and increased fire activity are expected to continue over the next century; and are likely to trigger rapid changes and reorganization of ecosystems as more drought and disturbance-tolerant species replace species pushed beyond their physical ability to adapt. In southern California, chaparral systems are already some of the most drought, heat, and fire-resistant ecosystems in North America (Keeley 1986, Haidinger and Keeley 1993, Davis and Michaelsen 1995), making them uniquely adapted to the projected warmer, drier future. However, for the agencies and individuals charged with administering these ecosystems, climate-driven changes to vegetation cover and increasing fire potential will bring a series of new challenges.

The Department of Defense manages more land in California than in any other state (1.5 million hectares (3.8 million acres)) (Gorte et al. 2012). Naval Base Coronado, situated along the San Diego coastline also administers a series of smaller inland training facilities located in and around the Southern California chaparral ecosystem. Training facilities at Camp Michael Monsoor (CMM) and Camp Morena (CM) are within the chaparral ecosystem, and Remote Training Site Warner Springs, located at slightly higher elevation, is situated along the eastern edge of the chaparral biome.

Over the past 25 years, almost two thirds of the greater southern California chaparral ecosystem has been affected by at least one fire (CalFire 2015), however, at the inland training sites more than 92% of land area has not experienced fire for more than 70 years (Calfire 2015). The effects of this fire deficit in a system generally considered to be dependent on high-intensity fires is not known. Additionally, the

effects and behavior of fire in chaparral systems that have been fire free for nearly a century raise concerns about system resilience and additional risks posed to infrastructure, training and operations, system function, as well as direct fire risks to humans and wildlife.

Project overview and problem statement

Training and NBC Inland sites

The inland training sites at CMM and CM are unique within the Department of Defense for their similarity in topographic characteristics, vegetative cover, and temperature extremes to conditions in central Asia and the Middle East where DoD is currently operating. Maintenance of the facilities and conditions appropriate for training is a priority to maintain operational readiness and ensure that deployed service members are optimally trained for the conditions they are likely to face. At CMM, the diverse landscape includes open grasslands and sagebrush scrub as well as dense closed chaparral and oak-shrub woodlands, providing a range of opportunities for training scenarios and development of specialty skillsets.

These unique training facilities are embedded within the Southern California Chaparral ecosystem, where the primary disturbance agent is high-intensity crown fire at 20-50 year intervals (Keeley and Keeley 1988). In addition to the challenges posed by a system adapted to high-intensity fire, the chaparral ecosystems at CMM and CM are also home to one endangered and several threatened wildlife and plant species (NAVY 2013). Recent studies also suggest that Southern California chaparral ecosystems are sensitive to changing climate, with specific reference to increasingly severe drought conditions and temperature extremes (Davis et al. 2002, Coates et al. 2015).

Wildfire concerns and California chaparral

California chaparral ecosystems are adapted to high-intensity crown fire, with species-specific adaptations that allow for resprouting from surviving rootstock or heat and chemical activation of seedbeds that allow chaparral ecosystems to reestablish shortly after fire (Keeley 1987). A series of studies assessing chaparral response to severe drought and more frequent fires found that *Ceanothus* species, one of the most abundant genera in Southern California Chaparral is more sensitive to drought than other chaparral species and is likely to be differentially affected by an increase in heat-related drought stress in the coming decades (Davis et al. 2002). Although the range of historical fire intervals and typical fire size patterns in Southern California Chaparral ecosystems remains a topic of debate

(Keeley et al. 1999, Minnich and Franco-Vizcaíno 2008) most studies suggest that a fire interval on the order of 30-40 years allows for the accumulation of sufficient dead shrub “skeleton” material to generate high-intensity crown fire that retains the diversity of chaparral species and adaptive traits. Fire intervals shorter than 20-30 years have been shown to reduce species diversity by selecting resprouting species over reseeding species (Haidinger and Keeley 1993) and, if repeated, can result in increased spacing of plants, reduction in shrub canopy density, and other structural changes that result in a change to lower-intensity surface fire that promotes establishment of invasive grasses and other introduced species (Keeley et al. 2008). While concerns over conversion of chaparral ecosystems to grassland systems as a result of increasing fire frequency have been discussed for more than three decades, relatively little is known about the risks posed by fire exclusion from chaparral ecosystems and how this might affect resilience under changing climate with or without fire.

Fire exclusion resulting in “old growth” chaparral species and structure has a number of potential ramifications that may influence management goals given the operational and training requirements of Naval Base Coronado. Crown fire in typical chaparral systems can result in flame lengths exceeding 8 meters (25 feet) under relatively mild wind conditions (Scott and Burgan 2005) with potential to reach more than 12 meters (40 feet) under Santa Ana wind conditions typical of late summer and early fall. High-intensity fires on or around NBC facilities can threaten infrastructure and human health through direct exposure to heat and smoke from fast-moving flaming fronts. These fires may also affect habitat of threatened and endangered species, although the specific impacts of fire on sensitive species such as the Quino Checker Spot Butterfly (*Euphydryas editha quino*) are not known.

Little information is available regarding changes to fuel structure, type, and loading resulting from prolonged absence of fire (Figure 1). Changes to species assemblage structure and age suggest continuous regeneration of resprouting species and loss of seeding species reproduction in chaparral after more than 80 years without fire (Keeley 1992). Changes to vegetation tolerance of extreme drought and increasing temperatures, fire behavior, post-fire recovery in old-growth chaparral systems, and the appropriate management actions needed to address these potential changes are not known.

Figure 1 Old growth California chaparral at Camp Michael Monsoor, CA. More than 90% of the land area of the two chaparral-based inland training facilities operated by Naval Base Coronado have no recorded history of fire in more than 70 years. Old chaparral is characterized by significant accumulation of larger diameter dead fuels, increased canopy spacing, and a species mix favoring resprouting species over seedling species.

Drought, Santa Ana winds, Climate change, WUI

In addition to the challenges posed by uncertainty regarding the managed landscapes of Naval Base Coronado, projected increases in the frequency, duration, and severity of regional drought conditions, uncertainty regarding changes to the length of season and strength of Santa Ana winds (Miller and Schlegel 2006, Hughes et al. 2011), continuing encroachment of private land ownership, and an increasing exurban population in interior southern California pose additional challenges for military operations, training, management of fires, and land stewardship obligations. While this study does not attempt to address these specific concerns, decisions made regarding management of chaparral-dominated landscapes should be informed by these additional important components.

Project Goals

In this SERDP supported research project we seek to better understand the risks posed by projected future climate conditions through a series of studies that provide context for threats to inland training facilities at Naval Base Coronado in relation to the greater Southern California Chaparral ecosystem. Specific goals of this project include: 1) determine if significant changes to chaparral vegetation types have occurred over the prolonged fire-free period on NBC inland training facilities that would limit applicability of findings from the greater Southern California Chaparral biome, 2) identify

recent fires and associated environmental conditions occurring in vegetation types consistent with CMM and CM, 3) assess post-fire recovery for primary vegetation types in these systems as a function of fire burn severity, and antecedent and post-fire environmental conditions; 4) identify conditions at regional and local scales that influence chaparral vegetation growth as a function of vegetation type and relative age. We expect that information generated from this study will provide useful context for management decisions and challenges posed by climate, fire, and managing for sustainable landscapes.

Methods

Data acquisition

Southern California chaparral study area

To standardize the map products used for classification of vegetation at CMM, CM, and surrounding vegetation types, we selected a series of off-the-shelf mapping products and then tested results with ground truthing. We started with a comparison of the LANDFIRE rapid refresh 2011 (LANDFIRE 2016) and USGS GAP (USGS 2015a) vegetation models for Southern California Chaparral. Based on Google Earth Imagery (Google 2015), the LANDFIRE product was selected as the best option for initial ground truthing. Ground truthing consisted of a network of 80 photo points distributed across the road-accessible spatial extent of the Southern California inland chaparral ecosystem. Points were located with a handheld Garmin GPSMap 62csx receiver loaded with LANDFIRE 2011 existing vegetation type (evt) base maps. At least five georeferenced photo points were taken within each of ten major vegetation types by synchronizing the clock on the gps track log to the clock on an Olympus PEN-1 digital SLR camera. Photos were matched to the nearest track point at 10 second intervals using GpicSync v1.32 software (GPicSync 2014). At each location photos were taken facing the four cardinal directions and at point center a substrate photo was taken to determine surface characteristics and herbaceous cover. By comparing mapped vegetation to photo point samples spanning the range of chaparral vegetation types, we determined that the LANDFIRE 2011 map overclassified recently burned landscapes as grasslands, even when dominant infilling vegetation was more characteristic of pre-fire chaparral species composition with a short grass understory (Figure 2). With further comparison to ground-truthed photo points, we determined that the earlier generation of LANDFIRE existing vegetation maps, which did not incorporate recent fire perimeters and modeled vegetation changes, was a more accurate classification of existing and previous chaparral vegetation. For all subsequent analysis, the original 2001 existing vegetation product (LANDFIRE 2016) was used for classification of

general vegetation types (Figure 3). The analysis area was defined by the spatial extent of contiguous interior chaparral dominated by vegetation types representative of the species mix on the two NBC installations. Total analysis area of the southern California chaparral ecosystem was approximately 192,780 hectares (476,375 acres).

Figure 2 Examples of recently burned dry-mesic chaparral misclassified as grassland in LANDFIRE 2011. These photo point locations were properly classified in LANDFIRE 2001, which was selected as the best general landscape-scale vegetation mapping product.

Fire History

Fire history of the southern California chaparral region was determined from mapped fire perimeters from the California State Fire database (CalFire 2015). The database spans the period from 1911 to 2014 and includes fire date, name, approximate size, and cause of ignition. Fire perimeters were clipped to the analysis area and assessed for relative fire size, proportion of burn severity class, and chaparral age (time since fire).

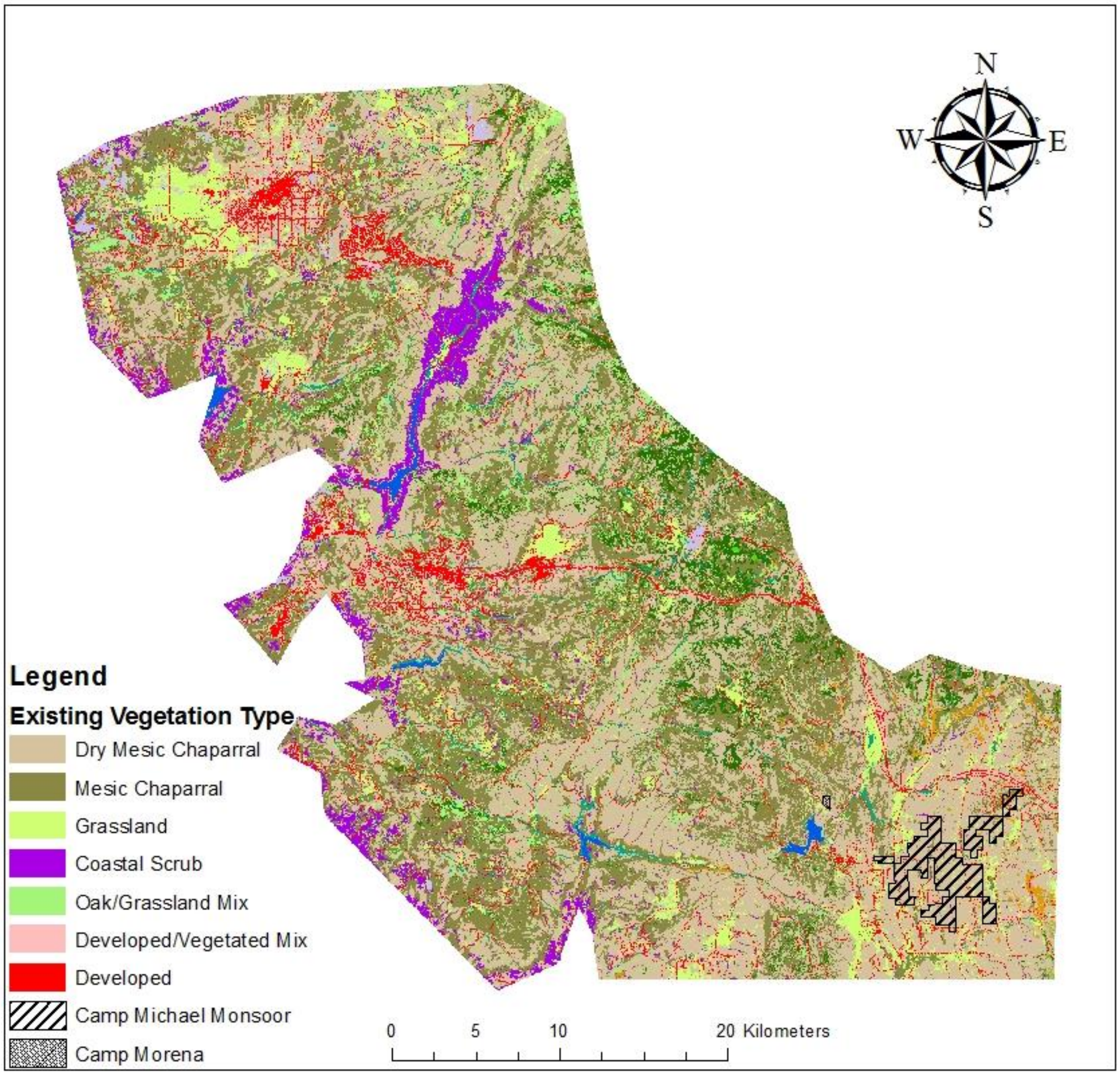


Figure 3 Spatial extent and species composition of Southern California interior chaparral. Inset of Camp Michael Monsoor (CMM) and Camp Morena (CM) in southeast corner of the bioregion. Vegetation types at CMM and CM are well represented throughout the study area. Vegetation classification is from LANDFIRE existing vegetation (2001) validated with 80 ground-truthed photo points.

Vegetation classes from the LANDFIRE 2001 existing vegetation map were simplified into six primary types, including DMC, MC, interior coastal scrub, Oak-grassland, grassland, and developed vegetated mix. Vegetation comprising less than 5% of total vegetated area was combined into “other” vegetation and was not included in remote sensing and fire analyses.

Analysis by vegetation age

Relative time since fire was used to test vegetation response to environmental conditions as a function of successional class and age (Figure 4). While vegetation type and relative species mix was

consistent throughout the study area, the spatial distribution of older chaparral was heavily weighted toward the southeast region of the ecosystem where NBC facilities are located.

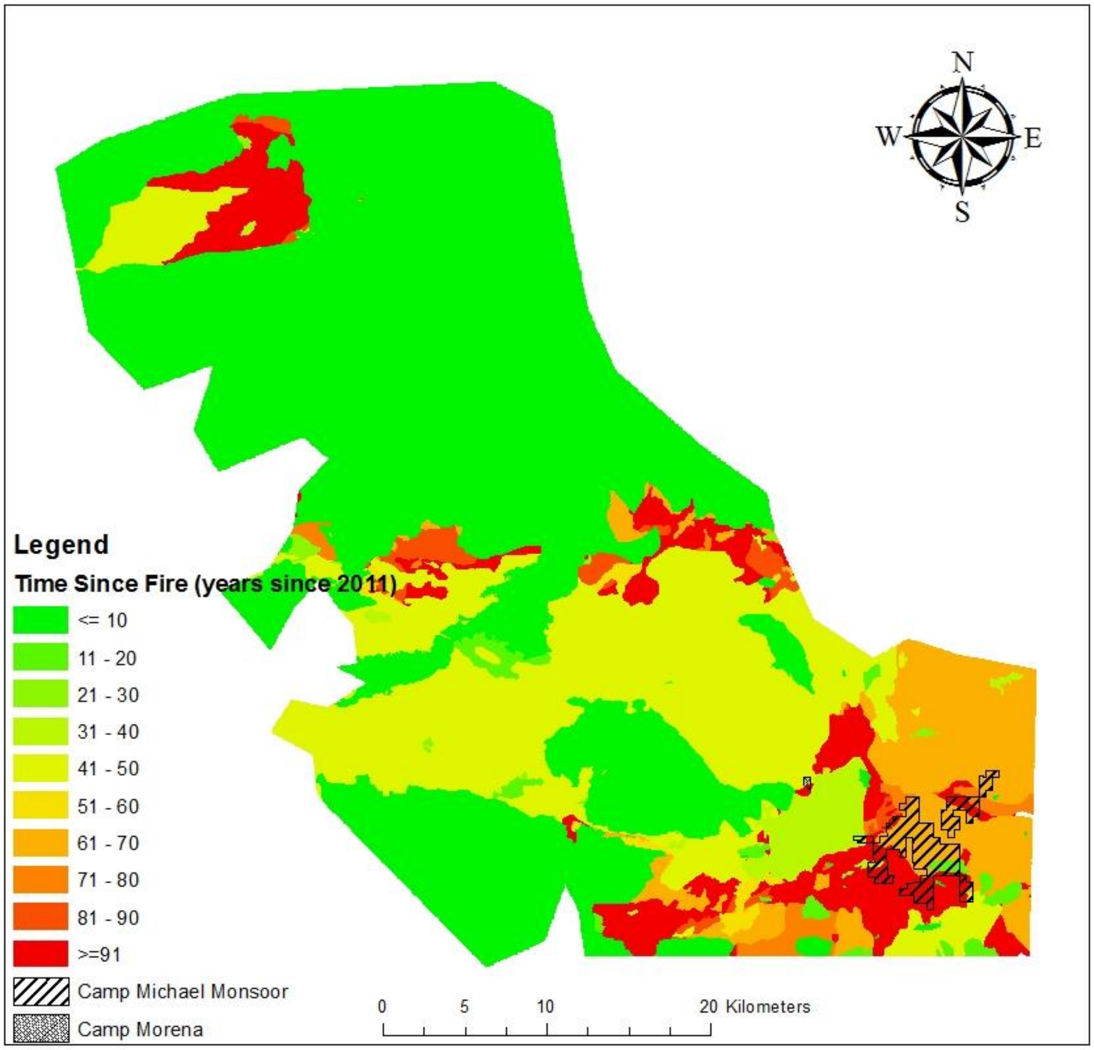


Figure 4 Relative age of chaparral types represented as time since fire. The majority of vegetated area has experienced at least one fire in the past 50 years. More than 90% of the combined CMM and CM area has not experienced fire in the past 70 years.

For analysis of vegetation response to environmental conditions, the landscape was classified into three vegetation age groups. Vegetation age groups were generated based on a combination of availability of standardized remote sensing vegetation indices (pre and post 1984 LandSat Imagery) and vegetation age in relation to expected fire return interval (greater than or less than 70 years since fire). The resulting three age classes from youngest to oldest: “post-LandSat fire” for landscapes that experienced fire since 1984 (vegetation < 27 years), “pre-LandSat fire” for landscapes with recorded fire

history only prior to 1984 (vegetation 28- 70 years), and “no recorded fire” (vegetation >71 years), were used for analysis of vegetation sensitivity to environmental drivers as a function of vegetation age.

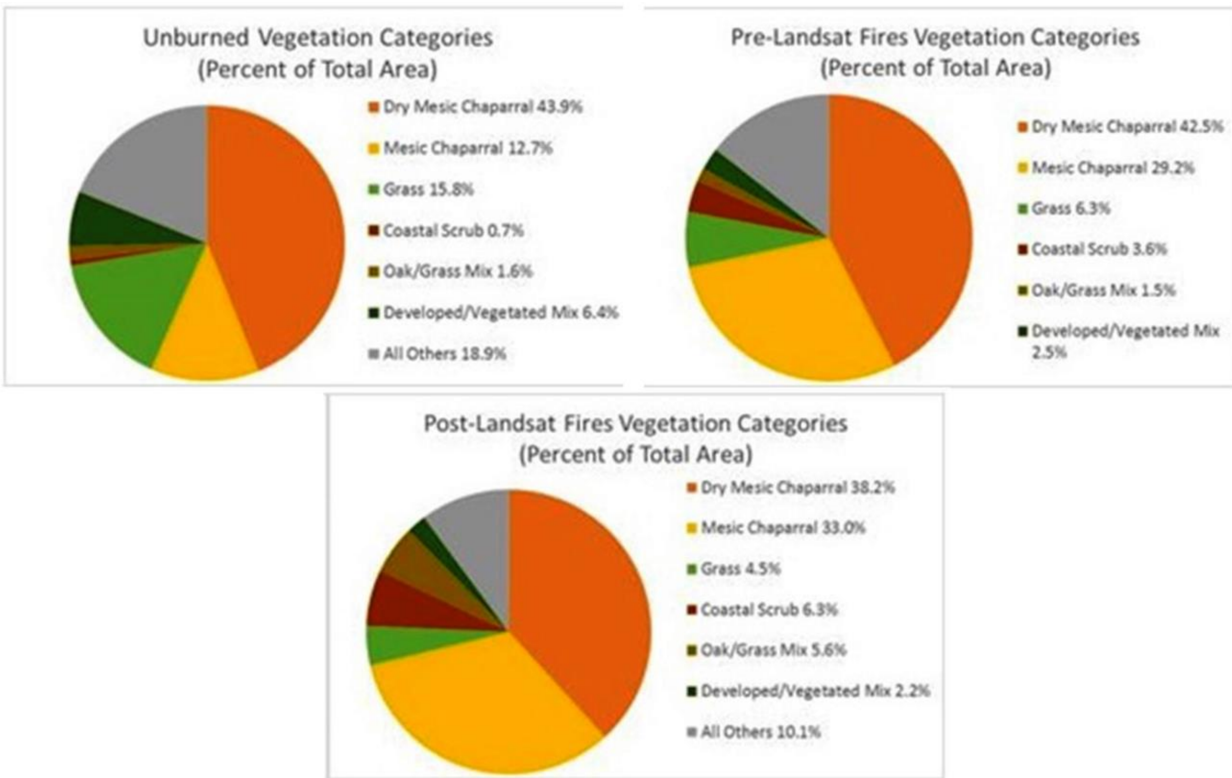


Figure 5 Proportion of dominant vegetation types by age class. All age classes are dominated by DMC and mesic chaparral. Minor components of grassland, coastal scrub, oak/grass mix, and developed vegetated mix vary in relative area as a function of time since fire and human land uses.

Remote sensing data

Normalized Difference Moisture Index (NDMI also known as NDWI) and Normalized Burn Ratio (NBR) are two standardized products available at 30 m resolution from the Landsat Thematic Mapper ™ Surface reflectance archive (USGS 2015b). NDMI is a direct measure of water absorption that is more sensitive to the chlorophyll-based normalized difference vegetation index (NDVI) and has been shown to more accurately capture moisture fluctuations, a proxy for plant stress, in southern California vegetation (Dennison et al. 2005). NBR is used to identify burned areas and measure the relative effect of fire on surface (vegetation) moisture measured as the ratio of change in middle infrared reflectance. We obtained NDMI and NBR data from every available scene from the Landsat TM Surface Reflectance archive (path 40/row 37) from 17 November 1982 to 9 November 2011. This resulted in over five hundred scenes for each index, though the number of scenes per year varied from one to 23.

Landsat TM scenes and quality assurance (qa) files were converted from GEOTIFF to .IMG format and "cloud_qa" and "cloud_shadow_qa" files (included for each Landsat scene) for each scene were then used to mask the NBR and NDMI scenes to identify cloud and cloud shadow pixels, respectively. For every scene, any pixel identified as cloud or cloud shadow was assigned a value of "NO DATA". Once this was done, the scenes were stacked by calendar year for both NBR and NDMI.

Scenes with greater than 10% cloud cover were determined to be of limited use and the vast majority (>90%) of scenes with more than 10% cloud cover were for scenes captured during the months of November through March. For the purposes of tracking moisture stress and potential fire conditions, the calendar year stacks of NBR and NDMI scenes were reduced to contain only images captured during the April to October dry season. This process had the added benefit of greatly improving the temporal consistency year to year.

EVT category *and fire history category* shapefiles were imported, converted to area of interest (AOI) files, and re-projected to match the Landsat TM scenes (from NAD 1983/UTM/Zone 10N to WGS 1984/UTM/Zone 11N). The yearly dry season NBR and NDMI stacks were then clipped to each of these AOI files. A mean raster layer was then created for each of these clipped stacks, where each pixel on the mean raster represents the arithmetic mean for that pixel for all layers of the stack. All of the mean raster layers were then stacked, creating a time series stack for each AOI (analysis area, each EVT category, and each fire history category) with each layer representing the mean pixel values for a given year's dry season.

Four individual fires were selected to more closely examine NBR and NDMI values leading up to, as well as after each individual fire event (Figure 6). Fires were selected based on the relative homogeneity of vegetation category within the burn area, proximity to the NBC installations, variability of fire burn severities (MTBS 2015), and range of sizes. The Bobcat fire that ignited August 1, 2002 was closest to CM and CMM and was the smallest and oldest fire used for analysis. The Cedar fire, the largest wildfire recorded in California to date, began on October 25, 2003 and affected approximately one third of the study area. The majority of the Cedar fire occurred in DMC and MC types with similar species to those at CMM. The Horse and Harris fires started on July 23, 2006 and October 21, 2007 respectively and were some of the largest recent fires in close proximity to the NBC installations.

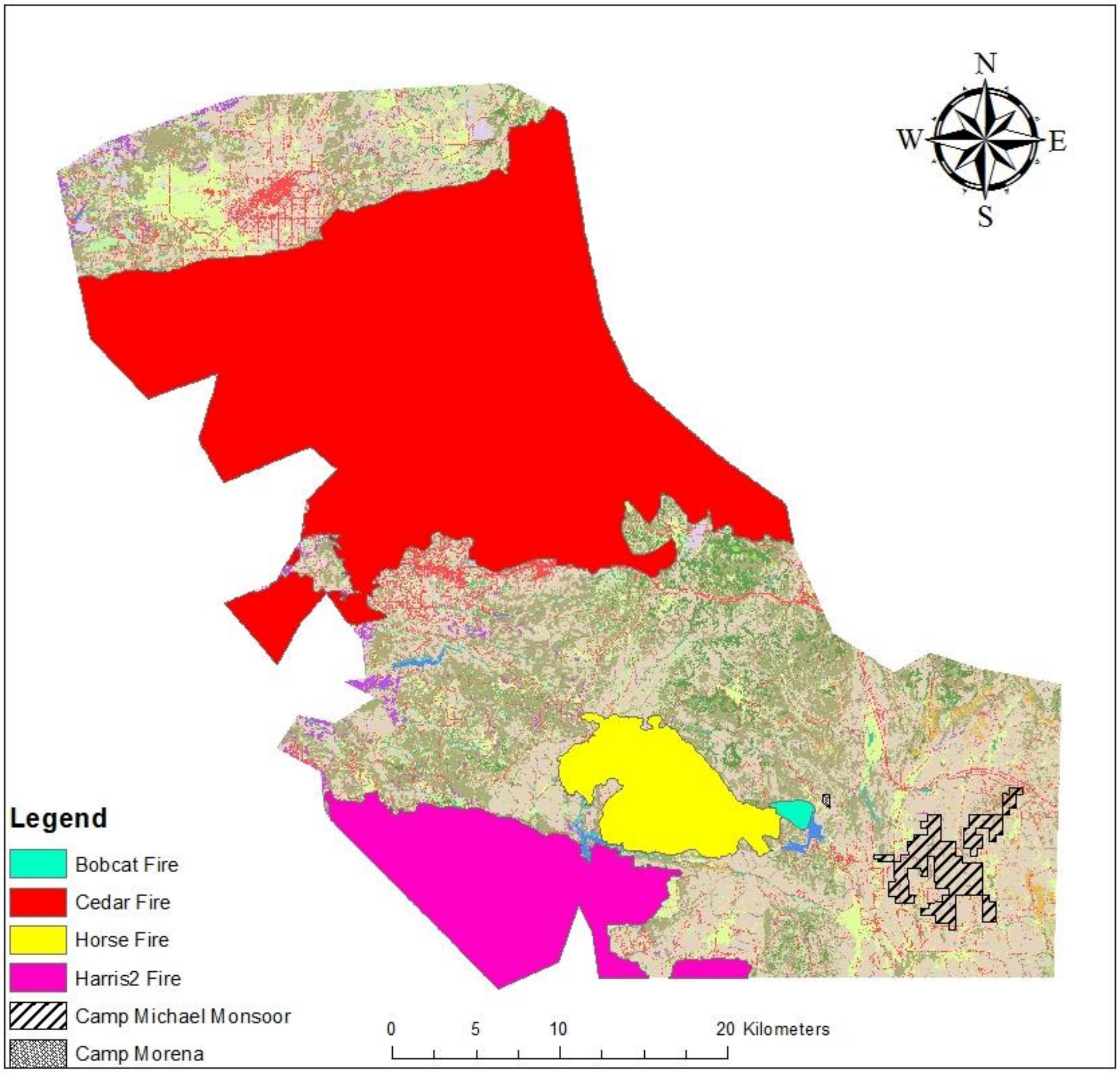


Figure 6 Four post-1984 fires used to assess post-fire recovery as a function of fire severity and pre-fire climate. Camp Michael Monsoor and Camp Morena share similar species with each of the selected fire perimeters.

NDMI and NBR associations with vegetation age

To test the difference in vegetation response to environmental conditions before and after fire, a series of "control" landscapes were defined that were not affected by the four fires used for analysis. The "no fire" control and "pre-landsat" control areas include the extent of the chaparral ecosystem around and including NBC installations that have no recorded fire or no fire since 1984 respectively (Figure 7). NDMI and NBR time series were generated for each of the six dominant vegetation types for three years before and after each fire to assess time to vegetation recovery in each of the four fires. NDMI and NBR values from fire-affected landscapes were standardized to values measured at control

unburned sites to generate a fire recovery index. The period of time when post-fire NDMI and NBR values were negative (in relation to control values) was used the quantify time to recovery for each vegetation type.

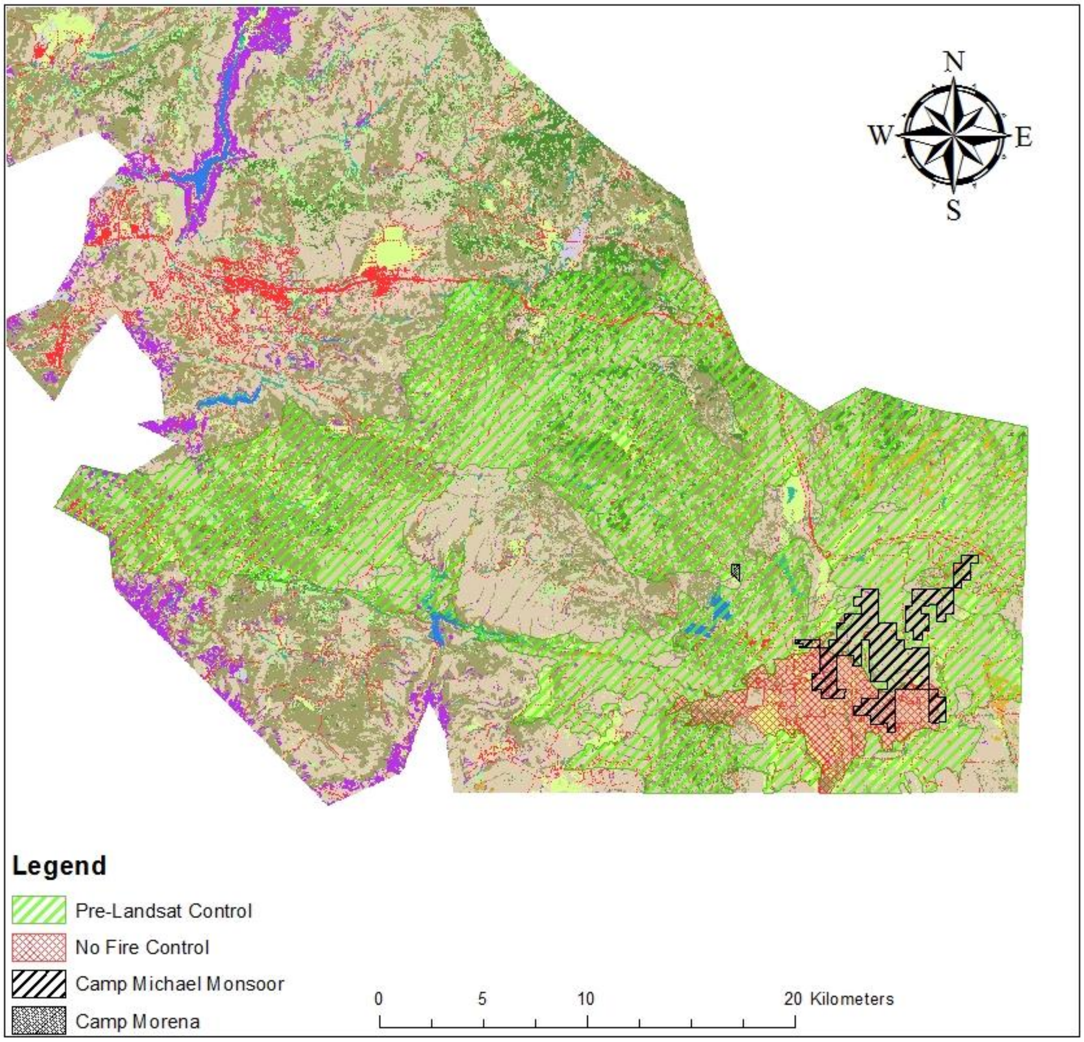


Figure 6 Pre-Landsat and No Fire control areas used to determine time to vegetation response recovery following recent fires. Control areas have not been exposed to fire for at least 27 years and are located in the southern region of the chaparral ecosystem near NBC inland training facilities.

Principal components analysis (PCA) of vegetation response

To determine the source of vegetation response (NDMI and NBR) variability for the period 1984 to 2011, we used a principal components analysis to determine relationships between species- specific NDMI and NBR values and a suite of environmental variables. For comparison at the scale of annual growing season, vegetation responses were averaged for each species over the curing season (April to October).

Environmental variables were converted to curing season indices for comparison to NDMI and NBR average values. Average, maximum, and minimum curing season temperature, and number of curing season days above 35° C (95° F), below 0° C (32° F) and with a minimum temperature above 15° C (59° F) were used to assess vegetation sensitivity to temperature (PRISM 2013). Total curing season precipitation and total number of days without rain were used to assess sensitivity to drought. Oceanic Niño Index (ONI) was used to assess the effects of El Niño and La Niña cycles on vegetation response (Niño 3.4 Region, 1982 – 2015, National Weather Service Climate Prediction Center). The ONI is determined by the mean sea-surface temperature anomaly for overlapping 3-month periods. Effects of El Niño Southern Oscillation (ENSO) events generally manifest in the Southwest during the spring following a sea surface temperature change event, so ONI was tested against both the curing season of occurrence and the curing season following an ENSO event to incorporate possible lag effects. ONI values were classified as “1” if >1, “0” if 1>0>-1, and -1 if <-1.

A Santa Ana Wind Index (SAI) was developed from airport wind gauge values from Miramar Airbase (Desert Research Institute 2015). Curing season and pre-curing season SAI were calculated from the number of days with easterly or southeasterly winds (200° <SAI<270°) with a minimum average daily wind speed of 5 m/s (11.2 mph) during the curing season and pre-curing season (prior November to March) respectively.

Results

Over the study period from 1984-2011 the six dominant species assemblages expressed a consistent pattern of NDMI response, suggesting a widespread top-down (climate) control on vegetation moisture at the landscape scale. Individual species assemblages exhibited different degrees of sensitivity, expressed as negative or positive deviation from the scaled zero value (Figure 7). Deeper rooted oak grass-mix and MC were least affected by the regional climate driver while shallow rooted open grassland, coastal scrub, and DMC were most sensitive to regional climate variability. All vegetation types expressed increased moisture stress during the 2002-2009 regional drought that was alleviated by the 2010 El Niño winter rains. As a result of the high correlation between vegetation response curves, we selected the two most prevalent vegetation types on NBC training sites and over the whole of the study area for further analysis of vegetation age and fire severity effects on climate sensitivity and post-fire recovery. DMC is the dominant vegetation at both CMM and CM followed by MC, grassland, coastal scrub, and developed vegetated mix (Figure 8).

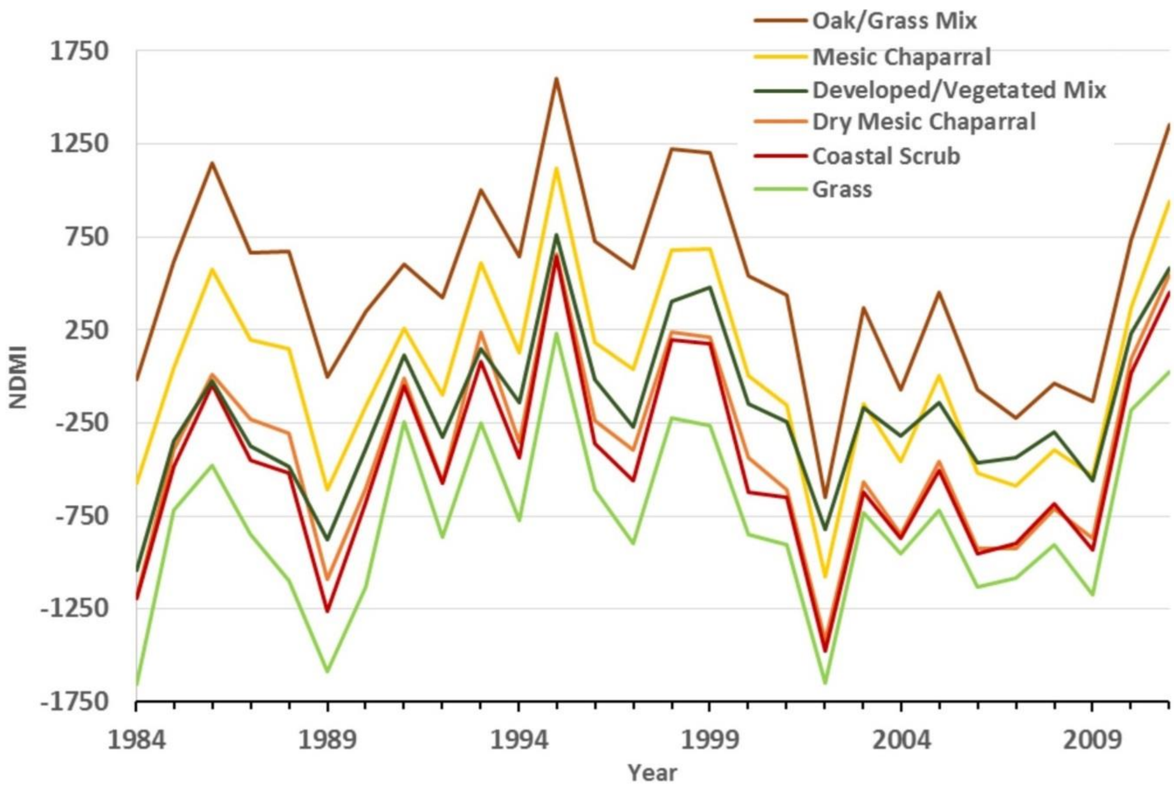


Figure 7 Vegetation response to moisture stress by dominant vegetation type. NDMI values below zero indicate increasing moisture stress, values above zero indicate reduced moisture stress. Grass, coastal scrub, and DMC were consistently the most moisture-stressed vegetation types. Oak grassland and Mesic Chaparral were consistently the least moisture stressed vegetation types.

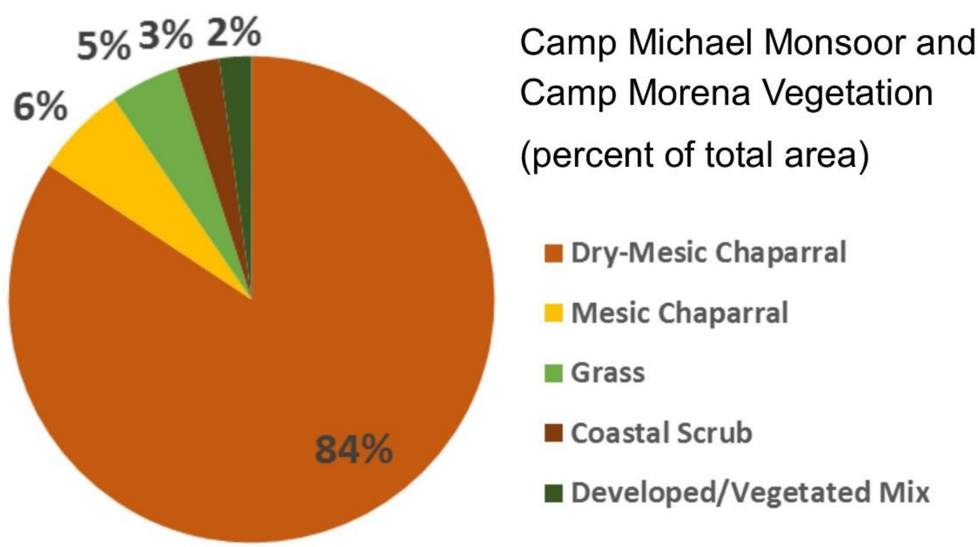


Figure 8 Vegetation composition at NBC inland training sites. Vegetation is dominated by Dry-mesic chaparral with minor components of mesic chaparral, grassland, and coastal scrub. Climate effects on dry mesic chaparral are most likely to affect operations at inland training sites.

Old growth DMC (>70 years) had significantly higher moisture stress than young DMC (<25 years) (Table 1, Figure 9). Moisture response curves of young and middle-aged (25-70 years) DMC assemblages were not distinguishable. A one-year temporary increase in moisture stress in the youngest DMC classes occurred in DMC affected by the Cedar Fire but not in those outside the fire perimeter.

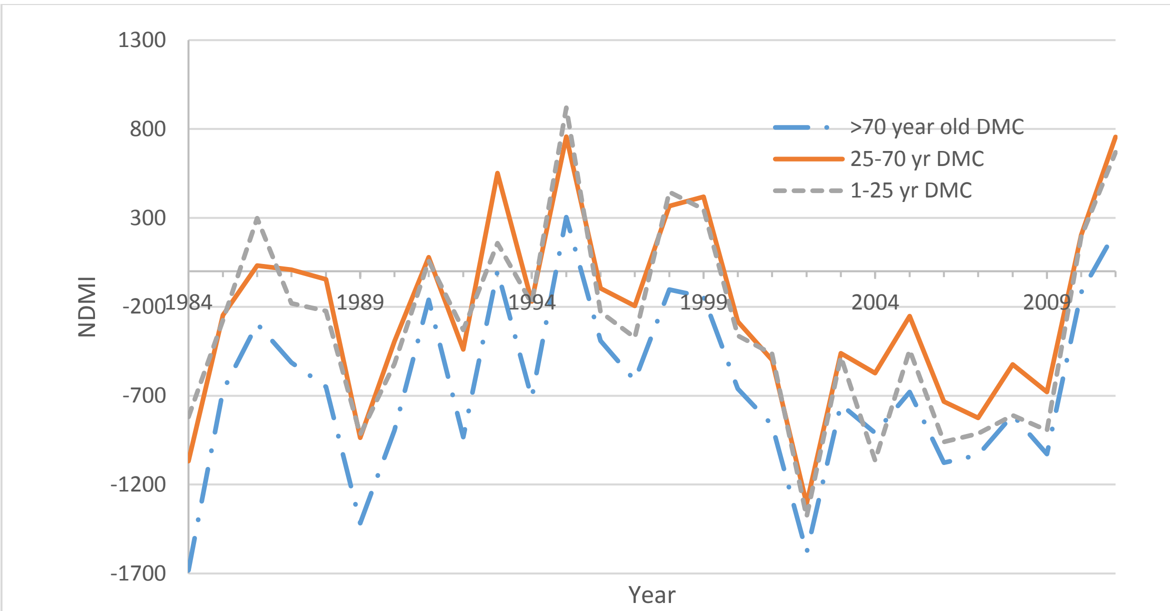


Figure 9 Dry Mesic Chaparral moisture stress as a function of time since fire. Dry-mesic chaparral was strongly affected by the 2000-2010 drought period. The oldest vegetation assemblages were consistently the most drought sensitive.

Chaparral age (time since fire) was not significantly associated with moisture stress in MC (Table 1, Figure 10), although the high-severity Cedar fire resulted in a nine-year increase in moisture sensitivity in the youngest MC vegetation class. Generally wetter conditions and deeper soils in this vegetation type may account for the reduced moisture sensitivity. *Middle aged (*27-70 years*) MC* was consistently less moisture stressed than older or younger stands. MC did not recover from the 2003 Cedar fire as quickly as the dry-mesic species assemblage, remaining highly drought sensitive for six years following fire. *MC* assemblages appeared to be more sensitive to high-severity fire than *DMC* assemblages and less sensitive to time since fire than their dry-mesic counterparts.

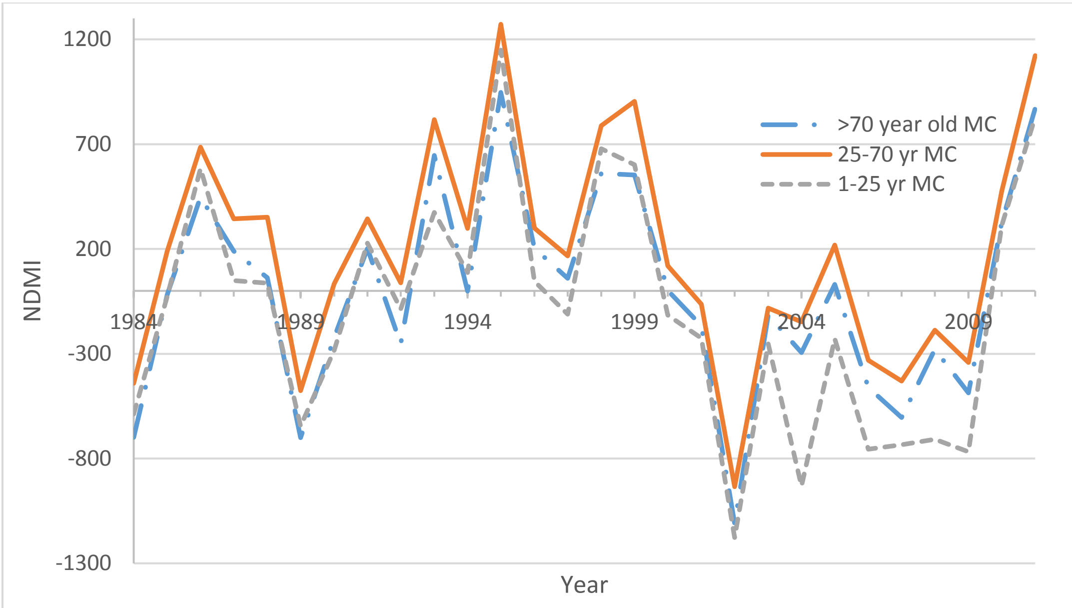


Figure 10 Mesic Chaparral moisture stress as a function of time since fire. Mesic chaparral was also strongly affected by the 2000s drought and 2003 Cedar fire, however the oldest age class was not any more sensitive to moisture stress that the youngest age classes.

Pairwise tests of NDMI difference for each set:

Table 1. Test of difference in drought response for vegetation older or younger than 70 years. Vegetation is partitioned into five dominant types (developed shrublands excluded). Median NDVI is a proxy for moisture response. Coefficient of variation is a measure of variability within vegetation type.

Vegetation age comparison	Median NDMI (*p*-value)	Coefficient of Variation (*p*-value)
Dry-Mesic Chaparral	0.0003*	0.9179
Mesic Chaparral	0.0956	0.3293
Grassland	0.3647	0.2134
Coastal Scrub	0.0028*	0.8906
Oak Grassland	0.8792	0.8284

Test within individual fires:

Burn severity of individual fires within the greater chaparral ecosystem was highly variable and was likely influenced by the mix of fuel types, topography, available moisture, and daily weather during each fire. The two smaller fires (Bobcat and Horse) were predominantly lower severity fires, with more than 70% low to moderate severity and approximately 10% high (stand replacing) severity (Figure 11).

In contrast, the larger Harris and Cedar fires burned at 25% and nearly 50% high severity respectively. Fire severity affected vegetation types differently depending upon their relative tolerance of stand replacing fire and rate of post-fire recovery.

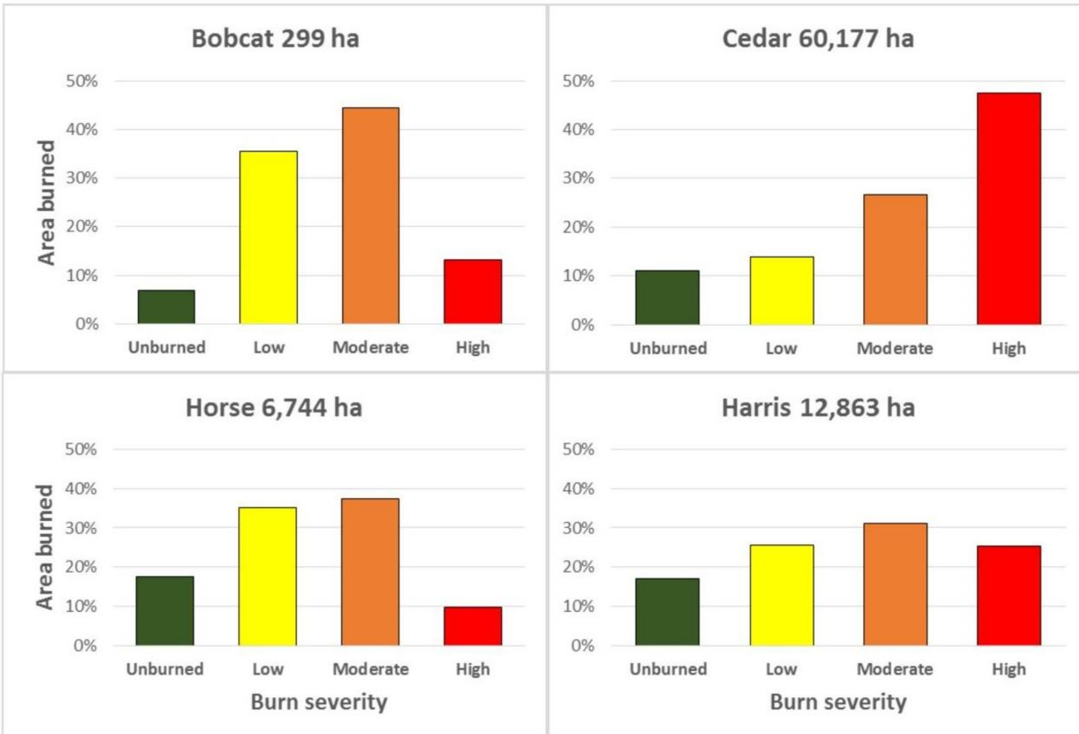


Figure 11 Proportional burn severity classes in four chaparral fires of variable size with vegetation similar to Camp Michael Monsoor.

Low-severity fires burning early in the fire season had little lasting effect on mesic or dry-mesic chaparral. Following both the Bobcat and Horse fires, all chaparral types returned to NDMI spectral signatures indistinguishable from control unburned vegetation within 1-2 years (Figure 12). Resilience of chaparral types in the smaller, lower severity fires was associated with the mild climate conditions more common early in the fire season. Recovery of mesic chaparral was somewhat slower in the larger sized Horse fire, but still returned to near pre-fire response within three years.

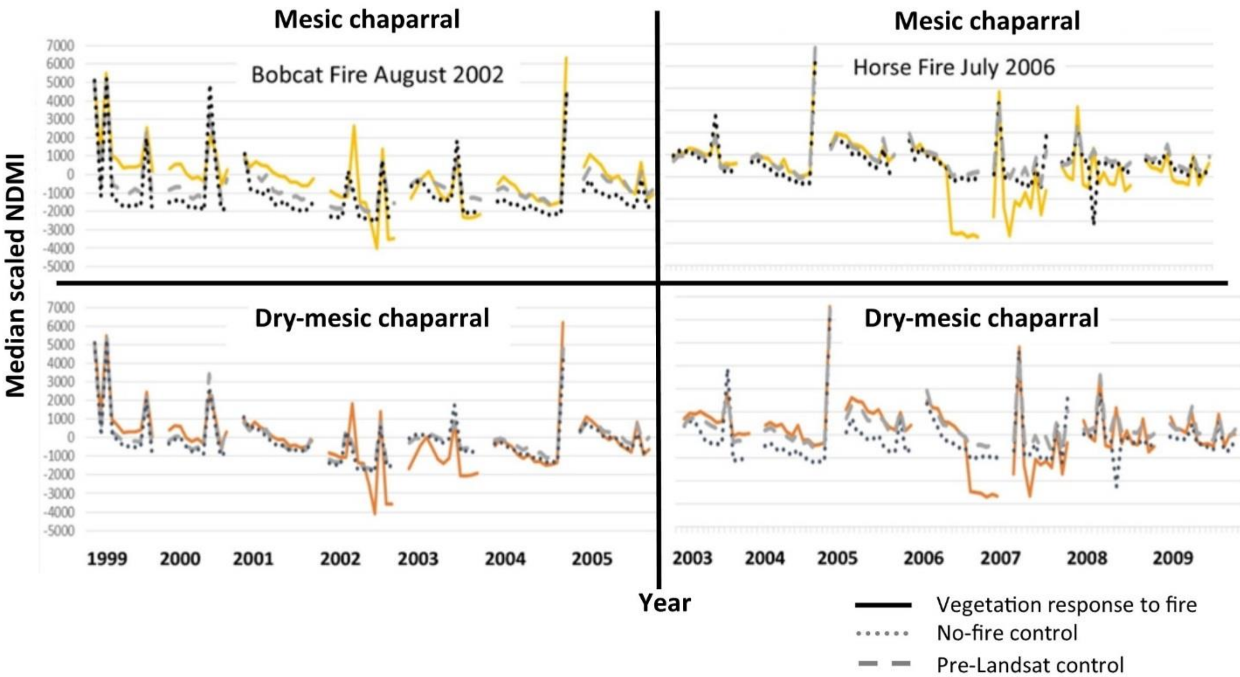


Figure 12 Chaparral response to low-severity fire compared to unburned controls.

DMC expressed a similar fast vegetation recovery following the larger, higher severity Cedar and Harris fires, returning to an NDMI spectral signature similar to that of unburned DMC within a year, during peak chaparral fire season and under extreme drought conditions (Figure 13). In contrast, MC stands expressed a significant negative response to high-severity fire that persisted beyond the three-year period of fire-severity testing. Burned MC did not recover to the NDMI spectral signature of pre-LANDSAT or old growth unburned chaparral for either age class.

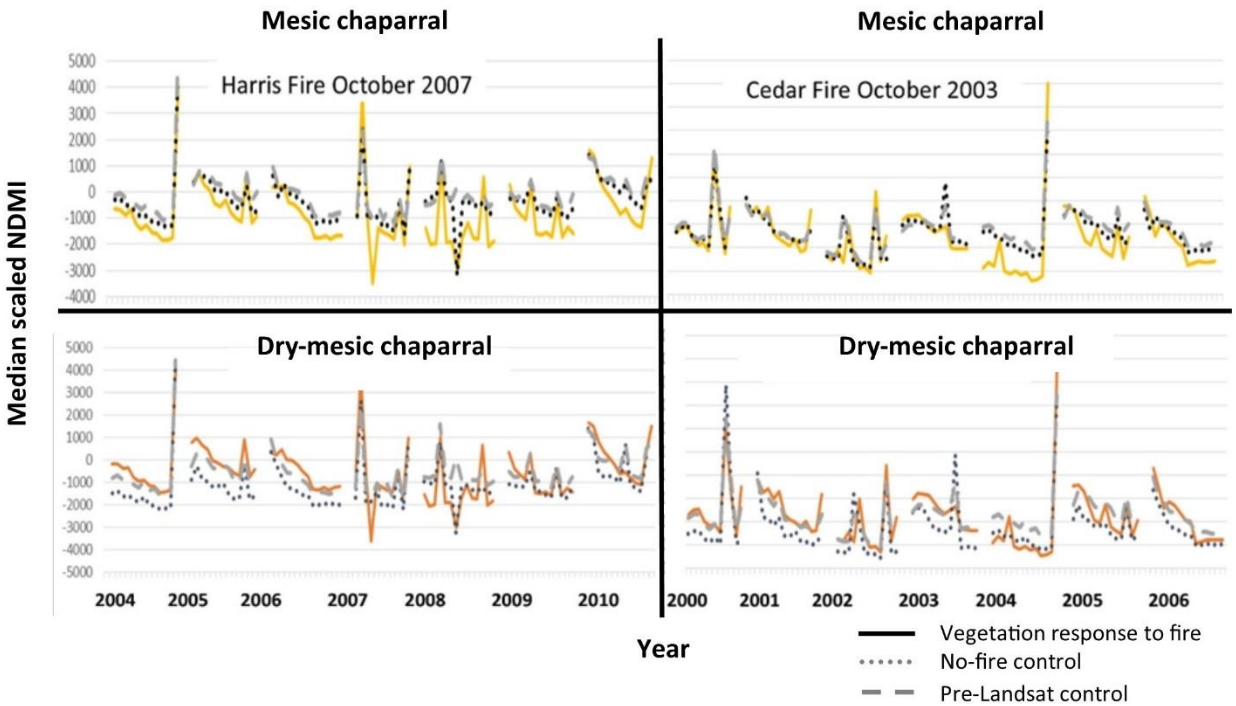


Figure 13 Chaparral response to large high-severity fires compared to unburned controls. Mesic chaparral expressed a delayed recovery following fires greater than 25% high severity. In both the Harris and Cedar fires, post-fire MC did not return to unburned vegetation response within the three-year window following fire. In contrast, DMC expressed similar vegetation response to unburned vegetation within a year following both fires.

Effects of post-fire climate on rate of recovery

Post-fire winter precipitation was directly correlated with vegetation recovery to pre-fire vegetation moisture index. The high-severity Cedar fire in the fall of 2003 was followed by above average total rain in the winter of 2003-2004 and may have offset some of the negative effects of high fire severity on all vegetation types affected. During the study period there was no example of a high-severity fire followed by persistent drought, a condition that has been found to slow recovery times in other vegetation types (e.g. Savage et al. 2013) and potentially facilitate conversion from chaparral to grassland or other more drought-adapted vegetation (Keeley et al. 2011).

Drivers of chaparral moisture stress response

The only environmental variable significantly associated with NDMI and NBR at the annual curing season (April to October) time step was mean curing season temperature. Curing season temperature was inversely related to NDMI and NBR. As temperature increased, water stress increased and NDMI (and NBR) values decreased. Mean curing season temperature explained 18-27% of the variance in NDMI for vegetation aged 25-70 years and 11-19% of the variance in NDMI for vegetation with no record of fire (100 or more years with no recorded fire) (Table2). The second most important

predictor of vegetation moisture stress varied by vegetation type and age, however the two most frequent secondary factors included days without rain (p-values 0.09-0.16), and pre-curing season Santa Ana Wind index (p-values 0.18-0.23), both of which were also inversely correlated with NDMI and positively correlated with water stress.

Table 2. Multivariate Redundancy Analysis of NDMI by vegetation type and independent climate proxy. Vegetation types are: DMC (dry-mesic chaparral), MC (mesic chaparral), GR (grassland), CoSC (coastal scrub), and OaGR (oak-grassland). Climate variables tested against median curing season (March-October) NDMI are mean curing season temperature, count of days over 35 °C, count of days without rain, pre-curing season Santa Ana Wind index, count of days below 0 °C, and count of days above 15 °C.

Table 2 RDA multivariate regression analysis of chaparral NDMI and climate

NDMI of vegetation 25-70 years since fire

Veg type	Mean temp (R^2)	p-value*	next-best	p-value	Total variance explained (all variables)
DMC	0.26	0.01	DaysOver35	0.13	0.53
MC	0.27	0.005	NoRainDays	0.11	0.49
GR	0.18	0.02	PreCS-SAI	0.18	0.59
CoSC	0.26	0.01	NoRainDays	0.15	0.55
OaGR	0.23	0.005	NoRainDays	0.09	0.48

NDMI of vegetation with no recorded fire

Veg type	Mean temp (R^2)	p-value*	next-best	p-value	Total variance explained (all variables)
DMC	0.15	0.035	days sub0	0.22	0.49
MC	0.19	0.015	preCS-SIA	0.2	0.37
GR	0.11	0.05	PreCS-_SAI	0.23	0.52
CoSC	0.19	0.025	DaysMin15	0.21	0.45
OaGR	0.18	0.01	NoRainDays	0.16	0.35

Summary of results

Vegetation assemblages on the driest sites expressed increasing sensitivity to temperature and associated drought conditions with increasing stand age, especially when time-since fire exceeded 70 years, suggesting that these “old growth” dry chaparral assemblages are more vulnerable to changing climate conditions than species growing on wetter sites. These same climate-sensitive assemblages were highly resilient to high-severity fire. All age classes of DMC recovered quickly following fire regardless of fire size or severity. Moisture stress in DMC was most strongly influenced by increasing mean temperatures, with less consistent associations to extreme high and low temperatures.

Chaparral assemblages with a tree overstory growing on mesic (wetter) sites showed no relationship between stand age and climate sensitivity. In general, variation in MC moisture stress was most strongly associated with increasing temperatures and less consistently influenced by days without rain and prior growing season Santa-Ana winds. Although MC was less sensitive to changing climate, fire severity had a stronger effect on post-fire recovery, such that increasing fire size and severity had a negative impact on the rate of MC recovery.

Discussion and management implications

Southern California chaparral ecosystems were less affected by seasonal drought and high temperatures when they had experienced at least one fire within the past 70 years. The dominant DMC system that comprises approximately 45% of the greater Southern California chaparral ecosystem and 84% of the two NBC managed sites appears to benefit most from regular cycles of high-severity fire. The second most abundant MC species assemblage appears to be less fire dependent and is well suited to small (<1000 ha) low and mixed severity fires but recovers more slowly from high-severity fires. In a series of studies of the effects of increasing fire frequency on chaparral systems, fires intervals less than 20 years were found to have potentially negative impacts on vegetation sustainability (Haidinger and Keeley 1993). Here we find that long-term exclusion of fire from this system beyond 70 years may have a similar negative effect. Together these studies suggest that a fire return interval between 20 and 70 years reduces climate stress and may promote retention of native species and assemblage structure. The only other vegetation type that showed increased moisture stress with age was the coastal scrub system, suggesting that both the DMC and coastal scrub systems are better suited to fire return intervals less than 70 years (Table 1).

Periodic recharge cycles

Over the 25-year period, NDMI across vegetation types tended to show a consistent negative trend for 4-5 years followed by a positive “recharge” spike coinciding with strong winter precipitation, perhaps associated with El Niño cycles. Any reduction in the frequency of these “recharge” events could result in a continual decline in plant available moisture, resulting in vegetative die-back and under extreme conditions, mortality of entire plants. *Ceanothus* species have been identified as the most drought-intolerant component of the chaparral ecosystem (Davis et al. 2002) and would likely be one of the first species complexes to be negatively affected by interruption of the cycle of periodic recharge events.

The magnitude of changing climate effects on winter precipitation cycles in Southern California is not well understood, thought the general trend from climate models suggests an over-all decline in winter precipitation over the next century. An increase in El Niño strength or frequency could offset this general trend of moisture reduction, however the converse is also true if El Niño cycles become weaker or less frequent.

Fire in chaparral systems

The negative effects of high-severity fire on chaparral ecosystems tend to be short lived, generally lasting from several months to a few years depending on the vegetation type. The species complex of chaparral ecosystems is uniquely adapted to high-severity fire, with resprouting and seeding strategies that promote rapid recovery even after extremely high-intensity fires (Keeley et al. 2008). This series of adaptations has been tested in other chaparral systems in southern and central California, where stand age (represented as time since fire) has been identified as an important component of post-fire resilience and resistance to invasion by introduced exotic grasses and shrubs (Keeley et al. 2008).

An increase in fire frequency resulting in re-burn of young chaparral stands tends to lead to more open chaparral growth forms that produce lower intensity fires. While this effect may be desirable for areas with infrastructure or sensitive wildlife habitat, high-frequency low-intensity fires in chaparral has been shown to promote invasion by exotic species that cannot tolerate the temperature extremes generated from typical high-intensity chaparral canopy fires. Thus thinning or controlled burning at frequent intervals may promote establishment of undesirable exotic species (Keeley et al. 2008).

We identified stand age as a driver of reduced chaparral fitness (measured as NDMI response) that may lead to more heat and drought-induced mortality and a reduction in chaparral species diversity with time since fire. The loss of sprouting species following long fire-free periods (exceeding ~80 years) (Keeley 1992) has implications for retention of habitat as well and an increase in invasibility of "old-growth" chaparral by introduced exotic species. From a fire perspective, a reduction in canopy density resulting from drought and heat-induced mortality could increase the proportion of dead fine fuels in the shrub canopy, promoting high-intensity fire, and allowing fire to purge invasive species and restore resilience to the system; or, if vegetation density is low enough to shift fire behavior toward a surface fire regime, the resulting low-intensity fire could facilitate invasion by exotic species, and with

subsequent fire at a short return interval, result in a type conversion from chaparral to more open shrub grassland.

The current policy of suppressing all fire near inland training facilities is unlikely to be sustainable over the coming decades. Projected increasing prevalence and duration of drought conditions is likely to continue to degrade old-growth chaparral ecosystems and increase the potential for invasion by non-native grasses. Allowing old growth chaparral to burn under moderate weather conditions (e.g. the fall prior to an El Niño event), is likely to result in reduced recovery time following fire and increased drought tolerance and adaptation to current and future climate conditions for at least the next several decades. One strategy to reduce the negative impacts from large high-severity fires on infrastructure and ecosystem values, would be the use of a managed fire approach with planned burn blocks that could facilitate a stepwise process of climate adaptation for inland sites while mitigating impacts on training and landscape management obligations.

Conclusions

The relationships between vegetation age and climate sensitivity revealed in this study demonstrate the value of place-specific case studies to identify unforeseen risks and address vulnerabilities at local and regional scales. Where risks are identified but uncertainty remains (as in this study), it will be important for land managers and operations personnel to be cognizant of potential threats to managed lands and to monitor and adjust daily operations and long-term management goals to promote stability and resiliency of desired landscape attributes while working to remediate undesired conditions.

Challenges raised by this study, such as the likely benefits of reintroducing fire to parts of DoD-managed lands, where little or no wildland fire management infrastructure exists, stress the importance of partnerships with surrounding state and federal institutions better positioned to manage landscape-level processes such as fire. Development of MOUs and other cross-jurisdictional agreements will allow DoD lands to make use of additional resources that promote long term stable and resilient landscapes that can support the training and operations missions of these unique facilities.

References

References

CalFire. 2015. Incident database. February 10, 2015. http://cdfdata.fire.ca.gov/incidents/incidents_statsevents.

Coates, A. R., P. E. Dennison, D. A. Roberts, and K. L. Roth. 2015. Monitoring the Impacts of Severe Drought on Southern California Chaparral Species using Hyperspectral and Thermal Infrared Imagery. Remote Sensing **7**:14276-14291.

Davis, F. W. and J. Michaelsen. 1995. Sensitivity of fire regime in chaparral ecosystems to climate change. Pages 435-456 Global change and Mediterranean-type ecosystems. Springer.

Davis, S. D., F. W. Ewers, J. S. Sperry, K. A. Portwood, M. C. Crocker, and G. C. Adams. 2002. Shoot dieback during prolonged drought in Ceanothus (Rhamnaceae) chaparral of California: a possible case of hydraulic failure. American Journal of Botany **89**:820-828.

Dennison, P., D. Roberts, S. Peterson, and J. Rechel. 2005. Use of normalized difference water index for monitoring live fuel moisture. International Journal of Remote Sensing **26**:1035-1042.

Garfin, G., G. Franco, H. Blanco, A. Comrie, P. Gonzalez, T. Piechota, R. Smyth, and R. Waskom. 2014. Ch. 20: Southwest. Climate Change Impacts in the United States. Pages 462-486 *in* J. M. Melillo, T. C. Richmond, and G. W. Yohe, editors. The Third National Climate Assessment. U.S. Global Change Research Program, Washington D.C.

Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy. 2013. Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment. Island Press, Washington, DC.

Google. 2015. Google Earth Pro v 7.1.4.1529. Southern California, USA. Google, SIO, NOAA, U.S. Navy, NGA, GEBCO. TerraMetrics 2015, INEGI. March 19, 2015. http://www.earth.google.com.

Gorte, R. W., C. Hardy Vincent, L. A. Hanson, and M. R. Rosenblum. 2012. Federal Land Ownership: Overview and Data. Congressional Research Service, Washington D.C.

GPicSync. 2014. GPicSync v1.3 photo georeferencing. GPicSync open source. http://gpicsync.software.informer.com/1.3/

Griffin, D. and K. J. Anchukaitis. 2014. How unusual is the 2012–2014 California drought? Geophysical Research Letters **41**:9017-9023.

Haidinger, T. L. and J. E. Keeley. 1993. Role of high fire frequency in destruction of mixed chaparral. Madrono **40**:141-147.

Hughes, M., A. Hall, and J. Kim. 2011. Human-induced changes in wind, temperature and relative humidity during Santa Ana events. Climatic Change **109**:119-132.

Keeley, J. E. 1986. Resilience of Mediterranean shrub communities to fires. Pages 95-112 Resilience in Mediterranean-type ecosystems. Springer.

Keeley, J. E. 1987. Role of fire in seed germination of woody taxa in California chaparral. Ecology:434-443.

Keeley, J. E. and S. C. Keeley. 1988. Chaparral. North American terrestrial vegetation.:165-207.

Keeley, J. E. 1992. Demographic structure of California chaparral in the long-term absence of fire. Journal of Vegetation Science **3**:79-90.

Keeley, J. E., T. Brennan, and A. H. Pfaff. 2008. Fire severity and ecosytem responses following crown fires in California shrublands. Ecological Applications **18**:1530-1546.

Keeley, J. E., C. Fotheringham, and M. Morais. 1999. Reexamining fire suppression impacts on brushland fire regimes. Science **284**:1829-1832.

Keeley, J. E., J. Franklin, and C. D'Antonio. 2011. Fire and invasive plants on California landscapes. Pages 193-221 *in* D. McKenzie, C. Miller, and D. A. Falk, editors. The landscape ecology of fire, Ecological Studies 213. Springer.

LANDFIRE. 2016. LANDFIRE LFDAT 2.6 National Fire Data Program. USDA Forest Service and U.S. Department of the Interior, Geological Survey. Web Page. http://www.landfire.gov/.

Miller, N. L. and N. J. Schlegel. 2006. Climate change projected fire weather sensitivity: California Santa Ana wind occurrence. Geophysical Research Letters **33**.

Minnich, R. A. and E. Franco-Vizcaíno. 2008. A probabilistic view of chaparral and forest fire regimes in southern California and Northern Baja California. Developments in Environmental Science **8**:339-364.

MTBS. 2015. Monitoring Trends in Burn Severity. USDA Forest Service RSAC. October 20. http://www.mtbs.gov/dataaccess.html.

NAVY, U. S. 2013. Final Integrated Natural Resources Management Program. Naval Base Coronado Final Environmental Assessment, United States Department of Defense, Navy Branch, Washington D.C.

PRISM. 2013. PRISM Climate Group, Oregon State University. http://www.prism.oregonstate.edu/

Savage, M., J. N. Mast, and J. J. Feddema. 2013. Double whammy: high-severity fire and drought in ponderosa pine forests of the Southwest. Canadian Journal of Forest Research **43**:570-583.

Scott, J. H. and R. E. Burgan. 2005. Standard fire behavior fuel models: a comprehensive set for use with Rothermel's surface fire spread model. RMRS-GTR-153, USDA Forest Service, Rocky Mountain Research Station., Fort Collins, CO.

USGS. 2015a. National Gap Analysis Program. United States Geological Survey. March 9, 2014. http://gapanalysis.usgs.gov/data/.

USGS. 2015b. U.S. Geological Survey Long Term Archive January 8, 2015. https://lta.cr.usgs.gov/get_data/.

Vose, R. S., S. Applequist, M. Squires, I. Durre, M. J. Menne, C. N. Williams Jr, C. Fenimore, K. Gleason, and D. Arndt. 2014. Improved historical temperature and precipitation time series for US climate divisions. Journal of Applied Meteorology and Climatology **53**:1232-1251.

7.2 List of Project Publications

Acclimatise, UK (2016) Learning from International Best Practices for Decision-Making in the Face of Climate Uncertainties: A Research Based Report for Project RC-2232.

Acclimatise, UK and UA SERDP Project RC-2232 Team (2015). Climate Change Impacts to Department of Defense Installations – Barry M. Goldwater Range Climate Risks Workshop Summary Report. Issued to BGR March 6, 2015.

Acclimatise, UK and UA SERDP Project RC-2232 Team (2014). Climate Change Impacts to Department of Defense Installations – Naval Base Coronado Climate Risk Report. Issued to NBC July 26, 2014.

Acclimatise, UK and UA SERDP Project RC-2232 Team (2013). Climate Change Impacts to Department of Defense Installations – Naval Base Coronado Climate Risks Workshop Summary Report. Issued to NBC May 17, 2013.

Garfin, G., D.A. Falk, C.D. O'Connor, K. Jacobs, R.D. Sagarin, A.C. Haverland, A. Haworth, A. Baglee, J. Weiss, J. Overpeck, A.A. Zuñiga-Terán. A new mission: climate adaptation challenges and opportunities in the Department of Defense. Submitted to Frontiers in Ecology and the Environment.

Jacobs, K (2016) The University of Arizona March 2016 Cross-Project Final Workshop Report . Submitted to SERDP May 2016.

O'Connor, C., G. Garfin, Falk, D. (2015) Projected climate change impacts on vegetation, fire, and wildlife habitat at Fort Huachuca, Arizona. Preliminary Report. Issued: June 23, 2015. 34 pp.

O'Connor, C., Sheppard, B., Falk, D. and G. Garfin. (2016). SERDP RC-2232 Interim Report 2: Quantifying post-fire flooding risk associated with changing climate at Fort Huachuca, Arizona. Technical Report to Ft. Huachuca, Department of the Army. Issued: March 2016. 32 pp.

O'Connor, C., Treanor, F., Falk, D., and G. Garfin. (2016) SERDP RC-2232 Interim Report 3: Climate change-type drought, temperature, and fire effects on Naval Base Coronado inland training sites, San Diego County, California. Technical Report to Naval Base Coronado, US Department of the Navy. 29 pp.Issued: June 2016.

Sagarin, R. and A. Zuñiga. (2015) Climate Change Adaptation in the Department of Defense Facilities of the Southwest. Barry Goldwater Range. Issued January 2015. 2 pp.

UA SERDP Project RC-2232 Team (2014) White Paper on Risk Assessment Methodology. Prepared by Project RC-2232 for the Strategic Environmental Research and Development Program. 64 pp.

UA SERDP Project RC-2232 Team and Acclimatise, UK (2015) White Paper on Climate Change Impacts and Adaptations on Southwestern DoD Facilities. October 8, 2015.

Weiss, J.L. (2014) Translation of Final Report from SERDP RC-1703 for Naval Base Coronado. 1 p.

Weiss, J.L. (2014) 2014 El Niño Event – Sea Level Rise Information Product for Naval Base Coronado. Issued: June 2014. 1 p.

Weiss, J., J. Overpeck, and R. Sagarin (2014) El Niño Event – Sea Level Rise Update for Naval Base Coronado. Issued: August, 2014. 6 pp.

Presentations and Proceedings

Garfin, G. (2016) Keeping it Off the Loading Dock: Climate Adaptation Engagement with the Department of Defense. Proceedings of the American Meteorological Society Annual Meeting in New Orleans, Louisiana. January 2016.

O’Connor, C. (2016) Projected impacts of climate change on vegetation and fire in the Huachuca Mountains of Arizona. Proceedings of the International Association of Wildland Fire Annual Conference in Portland, Oregon. April 2016.

O’Connor, C. (2016) Planning for a future of more fire, safer fire, and better fire. Proceedings of the International Association of Wildland Fire Annual Conference in Portland, Oregon. April 2016.

Sheppard, B., O’Connor, C., Falk, D and G. Garfin (2015) Modeling climate change impacts on landscape evolution, fire, and hydrology. Abstracts of the American Geophysical Union (AGU), San Francisco, California. December 2015.